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AEDC-TR-66-217

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PRESSURE TEST ON A 0.04-SCALE MODEL OF THE SATURN V LAUNCH VEHICLE AT MACH NUMBERS FROM 0.60 THROUGH 1.45

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ARO, Inc.

November 1966

PROPULSION WIND TUNNEL FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The work reported herein was done at the request of the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) under System 921E.

The results of the test presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted from August 19 through 26, 1966, under ARO Project No. PT1660, and the manuscript was submitted for publication on September 30, 1966.

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This technical report has been reviewed and is approved.

Richard W. Bradley
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ABSTRACT

Static pressure distribution and boundary-layer profiles were obtained on a 0.04-scale model of the Saturn V vehicle at Mach numbers from 0.60 to 1.45. The Reynolds number based on the model diameter varied from 3.3 to 6.0 million. Unsteady pressures were also measured over the full Mach number range; however, these data are not presented in this report. Protuberances on the model affected local static pressures, but did not alter the overall distribution significantly.

CONTENTS

ILLUSTRATIONS

NOMENCLATURE

A	Model reference area, $\frac{\pi D^2}{4}$, 1.368 ft^2
C_N	Total normal-force coefficient, $\int_0^L c_N\,dx$
C_p	Local pressure coefficient, $\frac{p - p_\infty}{q_\infty}$

c_N	Section normal-force coefficient, $\frac{2}{A} \int_0^1 C_p \frac{D_x}{2} d(\sin\phi)$
D	Model reference diameter, 1.320 ft
D_x	Model diameter at each sample section, ft
L	Model length, 13.819 ft
M_∞	Free-stream Mach number
p	Local static pressure, psf
p_{t_∞}	Free-stream total pressure, psf
p_∞	Free-stream static pressure, psf
q_∞	Free-stream dynamic pressure, psf
Re/ft	Reynolds number per foot, V_∞/ν_∞
U	Local velocity outside the boundary layer, ft/sec
u	Local velocity within the boundary layer, ft/sec
V_∞	Free-stream velocity, ft/sec
x	Model station aft of LES rocket nose, ft (Fig. 3)
y	Vertical distance above model surface, in.
α	Angle of attack, deg
ϕ	Roll angle, deg
ν_∞	Free-stream kinematic viscosity, ft^2/sec
ψ	Angle of model orifice meridian (Fig. 3), deg

MODEL NOMENCLATURE

APU	Auxiliary propulsion unit
LEM	Lunar excursion module
LES	Launch escape system
S-IC	Saturn-IC (first stage)
S-II	Saturn-II (second stage)
S-IVB	Saturn-IVB (third stage)

SECTION I
INTRODUCTION

The primary objective of this test was to determine the fluctuating pressure environment on a 0.04-scale model of the Saturn V launch vehicle. Secondary objectives were to determine the effects of protuberances on the dynamic and steady-state pressure environments, and to determine a static pressure distribution over the model surface for a structural loads analysis.

For these purposes two model configurations were tested in the Propulsion Wind Tunnel, Transonic (16T). Configuration 1 was equipped with all external protuberances and tested at angles of attack from -4 to +4 deg and roll angles of zero and 60 deg. Configuration 2 was stripped of all external protuberances and tested at angles of attack from -10 to +10 deg and roll angles of 0, 15, 30, and 60 deg. Both configurations were tested at Mach numbers from 0.60 through 1.40, and configuration 2 was tested at an additional Mach number of 1.45.

Several Mach sweeps from 0.75 through 1.00 were made for each configuration to verify that no phenomena were missed by taking data in finite Mach number steps.

SECTION II
APPARATUS

2.1 WIND TUNNEL

The Propulsion Wind Tunnel, Transonic (16T) is a variable density tunnel which has a 16-ft-square test section with perforated walls to allow continuous operation through the Mach number range from 0.55 to 1.60 with minimum wall interference. A more thorough description of the tunnel may be found in Ref. 1, and applicable calibration results are presented in Refs. 2 and 3.

A schematic of the tunnel test section showing configuration 1 installed is presented in Fig. 1.

2.2 TEST ARTICLE

Installation photographs of configurations 1 and 2 are shown in Figs. 2a and b. Configuration 1 had the external features of the

full-scale vehicle with all protuberances, such as auxiliary propulsion units (APU), instrumentation tunnels, fins, and aerodynamic shrouds. Configuration 2 was clean, derived by removing all protuberances from the model. Photographs showing the protuberances, instrumentation, and rake details are presented in Figs. 2c, d, and e, and a detailed drawing of both configurations is presented in Fig. 3.

Figures 4a and b show the five boundary-layer rakes used on both configurations. Each rake pivoted about a point inside the model and provided a flush model surface when extended or retracted. The rakes were located along the 130-deg meridian (Fig. 3) and were extended individually by remote control.

2.3 INSTRUMENTATION

A schematic of the general instrumentation arrangement is shown in Fig. 5.

2.3.1 Steady-State Measurements

Static pressures were measured from 320 orifices, 233 of which were located on the 180-deg meridian (top centerline). Fifty-three orifices located in the S-IVB flare region at meridian angles of 5.62, 19.50, 36.25, and 78.75 deg provided a means of determining the interstage interference as well as protuberance disturbances on local pressures. In the shroud-fin region, 34 additional orifices were located at meridian angles of 22.50, 33.75, and 43.00 deg, and were staggered along the shroud to determine local pressure levels in this area. Photographs showing some of the orifices are presented in Figs. 2d and e.

Boundary-layer data were obtained from 61 total pressure probes housed in five retractable rakes.

The 381 pressures from these sources were measured using ten 48-port pneumatic switches having self-contained, differential strain-gage pressure transducers.

2.3.2 Unsteady Measurements

A total of 140 flush-mounted microphones was used to measure the unsteady pressures on the model surface for all test conditions. Five other microphones were mounted inside the model to determine the influence of the model vibrations on the microphone outputs. The output signals from these microphones were conditioned by miniature charge

amplifiers, also mounted within the model in close proximity to the microphones. The output signals were recorded on magnetic tape.

Ten accelerometers were also located inside the model to give an indication of the vibration level. The signals from these accelerometers were also recorded on magnetic tape.

SECTION III
TEST DESCRIPTION

3.1 TEST PROCEDURE

Both configurations were tested at Mach numbers from 0.60 through 1.40 at total pressures from 1275 to 2800 psf. Configuration 2 was also tested at Mach number 1.45 and a total pressure of 1425 psf. The variation of Reynolds number with Mach number for the test is given in Fig. 6. The model with all protuberances (configuration 1) was tested at angles of attack from -4 to +4 deg and roll angles of zero and 60 deg. The clean model (configuration 2) was tested at angles of attack from -10 to +10 deg at roll angles of 0, 15, 30, and 60 deg.

For a given Mach number, the model was pitched through the angle-of-attack range, and dynamic and static data were recorded consecutively at each pitch angle. The model was then rolled, and data were again taken until all roll angles were completed. Boundary-layer data were also taken at each Mach number, but only with the model at zero roll and zero pitch angles.

Several Mach number sweeps from 0.75 through 1.00 were made at total pressures of 500, 1100, and 1700 psf, and dynamic data were recorded throughout each sweep.

3.2 PRECISION OF MEASUREMENTS

The uncertainties in setting and maintaining tunnel conditions are estimated to be as follows:

Mach Number	±0.005
Total Pressure	±5 psf
Total Temperature	±5°F
Angle of Attack	±0.1 deg
Roll Angle	±0.1 deg

The Mach number uncertainty does not include the longitudinal variation on the tunnel centerline, which reaches a maximum of ±0.007.

SECTION IV
RESULTS AND DISCUSSION

4.1 STATIC PRESSURES

A compilation of the pressure distributions on the top centerline of the model (180 deg meridian) is presented in Fig. 7 for all of the Mach numbers at which the test was conducted. The plots are discontinued at a model station of 8 calibers since no appreciable change was experienced beyond this point. In most cases comparison of data from configurations 1 and 2 shows that the protuberance effects on the entire model are negligible from a macroscopic viewpoint; however, certain local discrepancies are noted, particularly in the S-IVB interstage area.

Figure 8 shows the effect of protuberances on local pressures within the S-IVB flare region. For configuration 1 the orifices at ray angles of 5.62 and 19.50 deg were in the immediate vicinity of protuberances and showed more variation than did the rays at 36.25 and 78.75 deg. Pressures measured from the last two rays followed closely the pressures measured on the clean model. The 36.25- and 78.75-deg meridians were 2.5 and 3.4 in., respectively, from the nearest protuberance, measured circumferentially.

Figure 9 shows the disturbance created by the aerodynamic shroud. The variation is seen to be more gentle than in the S-IVB region, probably because of the shroud design and the thicker turbulent boundary layer in this region.

4.2 BOUNDARY-LAYER MEASUREMENTS

For all boundary-layer data the reference velocity (U) for each rake was calculated using tunnel total pressure and a local reference static pressure (Fig. 4) which was nearest to the rake model station.

Boundary-layer profiles from four of the five rakes of configuration 2 are shown in Fig. 10 for several Mach numbers. Rakes 1 and 2 exhibit the greatest change with Mach number and appear to be entirely within the boundary layer. Rakes 4 and 5 indicate well-developed turbulent boundary layers of the thicknesses from 2.0 to 2.5 in.

Rakes 4 and 5 showed a more noticeable change because of protuberance effects, and Fig. 11 shows a typical example of this disturbance. For configuration 1 at Mach number 0.90, the two rakes are seen to have random variations for vertical distances less than one inch from the model surface. Since rake 4 is far upstream of the shrouds, it must be concluded that the major part of these disturbances is created by upstream protuberances. The well-behaved profiles for the clean model rule out effects caused by the flare-shoulder upstream.

4.3 CALCULATED NORMAL-FORCE COEFFICIENT

In order to allow a means of comparison between these results and those presented in Ref. 4, a total normal-force coefficient was calculated. Pressures from selected orifices along the 180-deg meridian line were used with the model at four roll positions (0, 15, 30, and 60 deg) and angles of attack of -10 and +10 deg. The section pressure coefficients were plotted against the sine of their respective roll positions, and a direct integration was performed to give the section normal-force coefficient.

Data presented in Ref. 4 indicate that the maximum normal-force coefficient for this model can be expected at a Mach number of 1.00. Accordingly, the section coefficients were calculated at fourteen locations on the clean model (configuration 2) at a 10-deg angle of attack, and these coefficients are presented in Fig. 12. Graphical integration of this plot gives a value for total normal-force coefficient of 0.948. The measured force data as presented in Ref. 4 for a model with shrouds and fins, give a value of 1.000 at these conditions. The discrepancy can be attributed largely to the effects of the shrouds and fins.

REFERENCES

1. Test Facilities Handbook (5th Edition). "Propulsion Wind Tunnel Facility, Vol. 3." Arnold Engineering Development Center, July 1963.

2. Chevalier, H. L. "Calibration of the PWT 16-Foot Transonic Circuit with a Modified Model Support System and Test Section." AEDC-TN-60-164 (AD 241785), August 1960.

3. Chevalier, H. L. and Todd, H. E. "Measurement of the Pressure Fluctuations in the Test Section of the 16-Foot Transonic Circuit in the Frequency Range from 5 to 1000 CPS." AEDC-TN-61-51 (AD 255763), May 1961.

4. Henson, Victor K. "Static Aerodynamic Characteristics of the Apollo-Saturn V Vehicle." NASA TM X-53307, July 26, 1965.

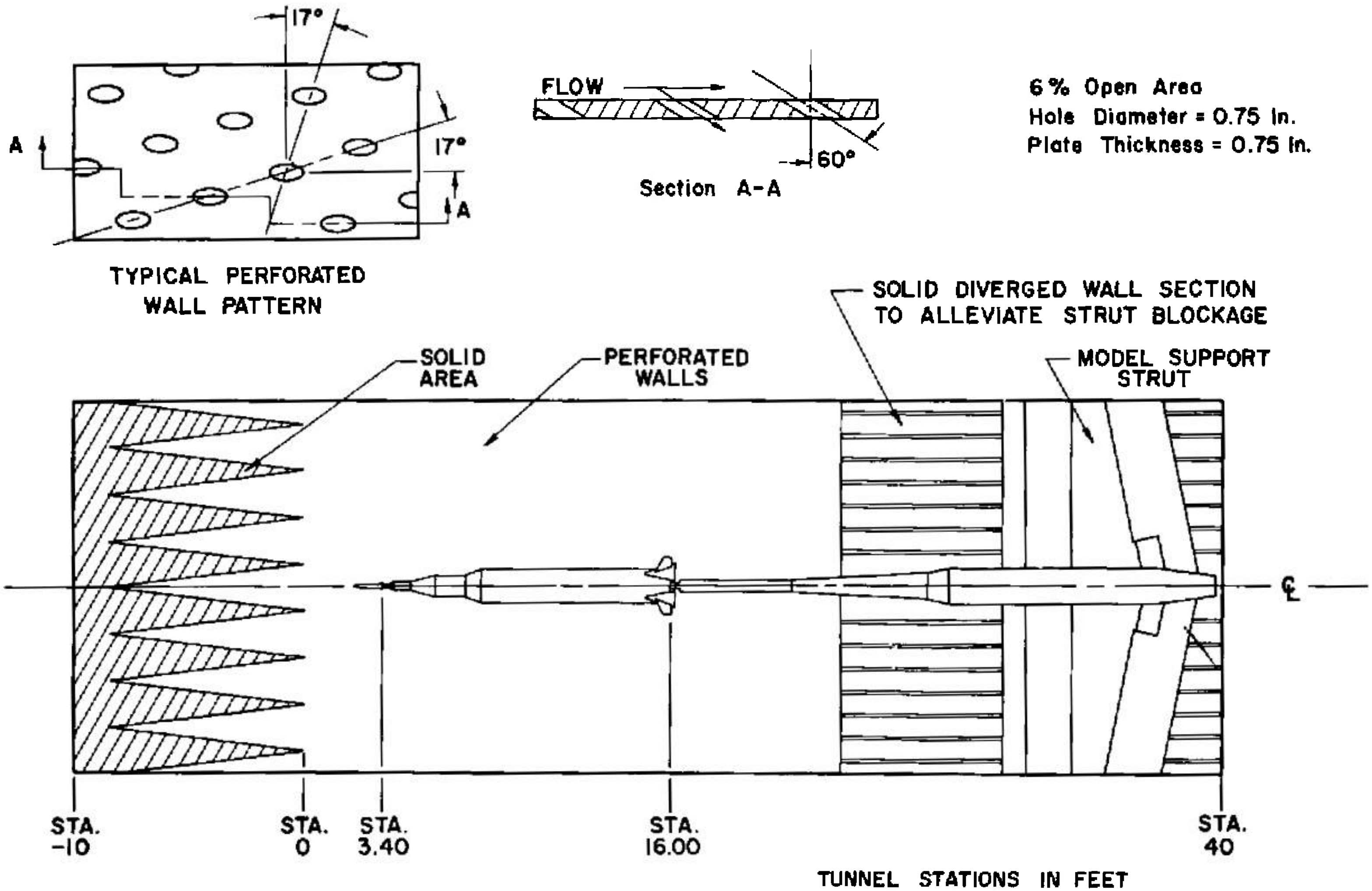
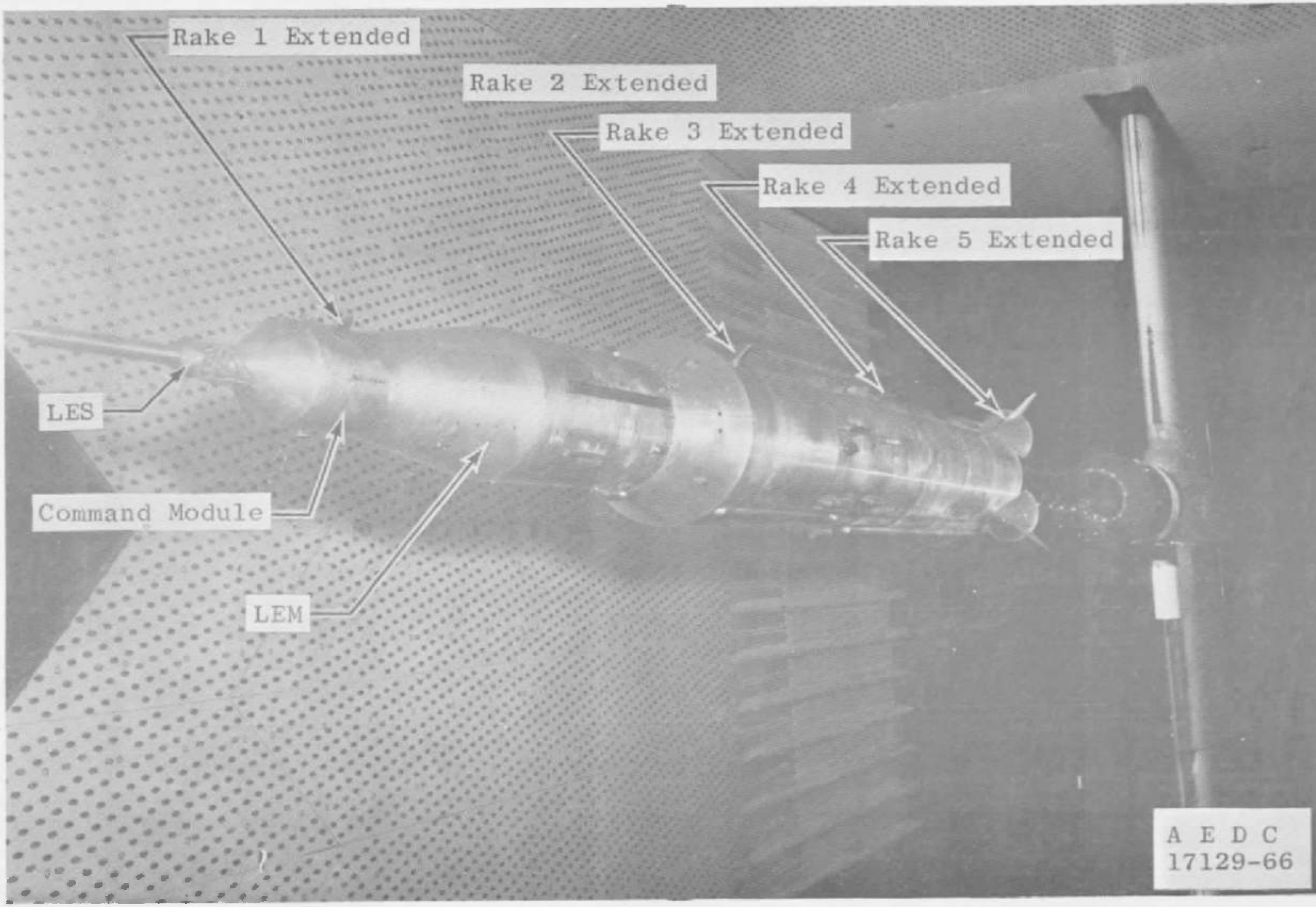
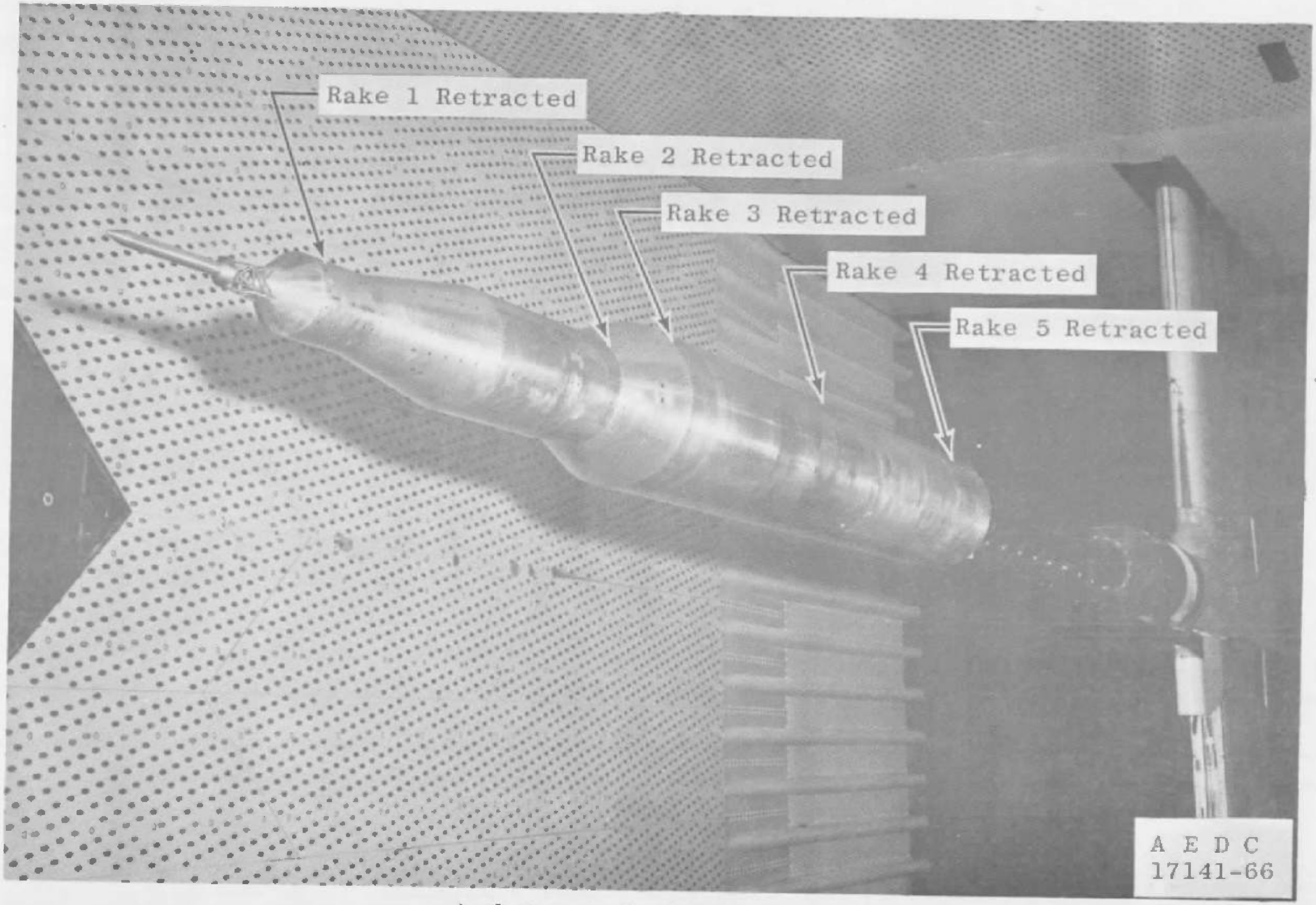


Fig. 1 Schematic of Saturn V Model in PWT-16T Test Section



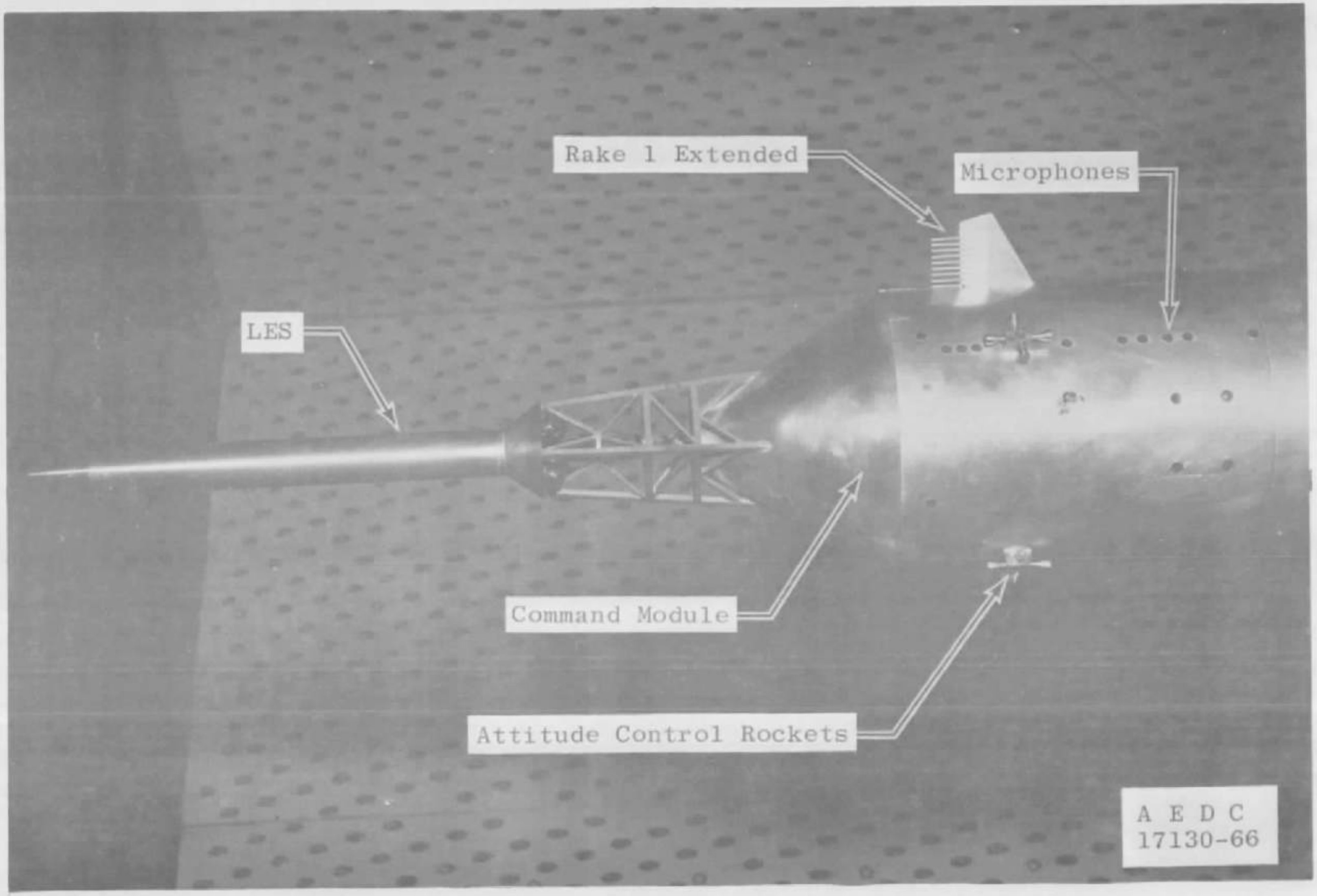
a. Configuration 1 in 16T Test Section

Fig. 2 Installation Photographs of Model in Tunnel

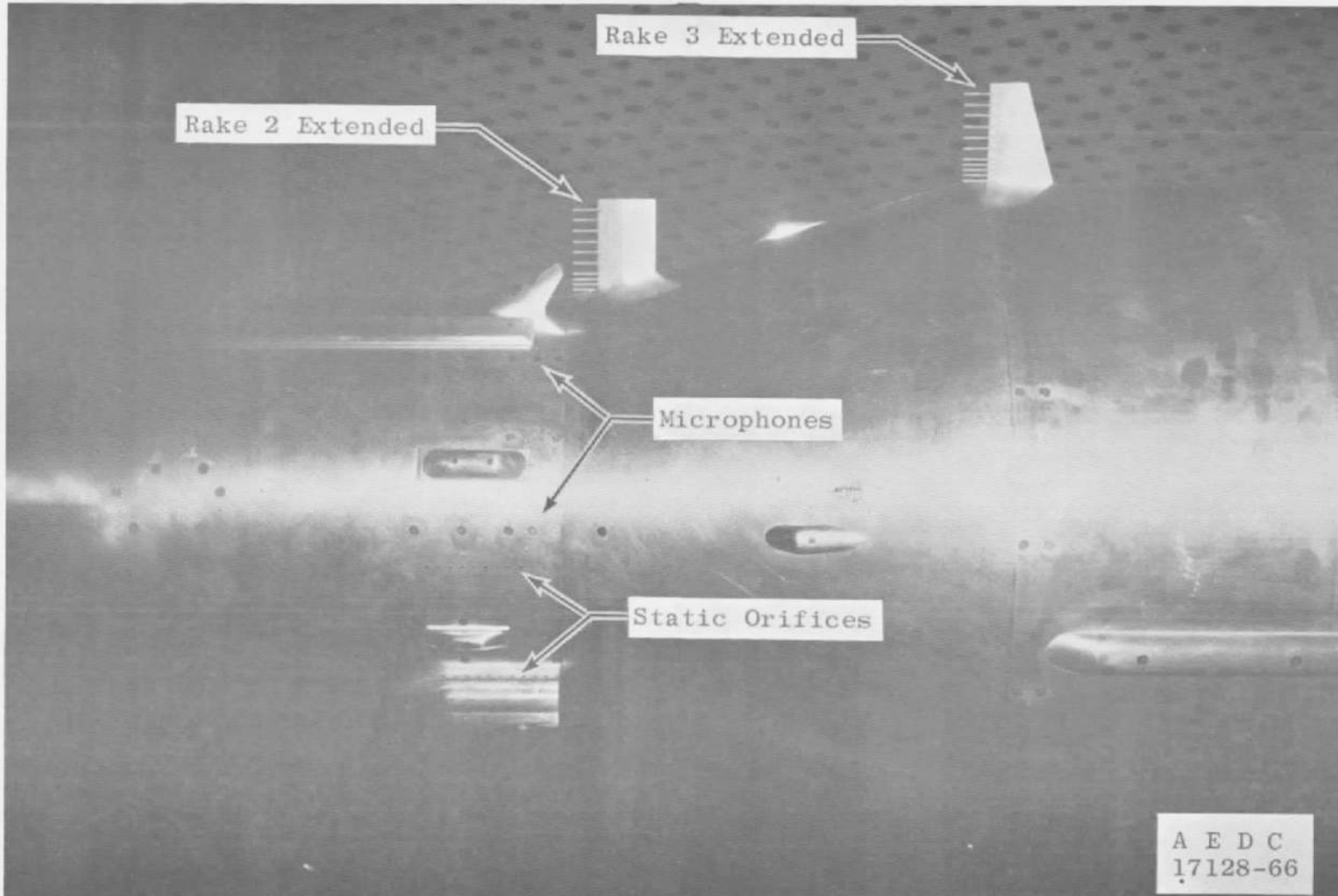


b. Configuration 2 in 16T Test Section

Fig. 2 Continued

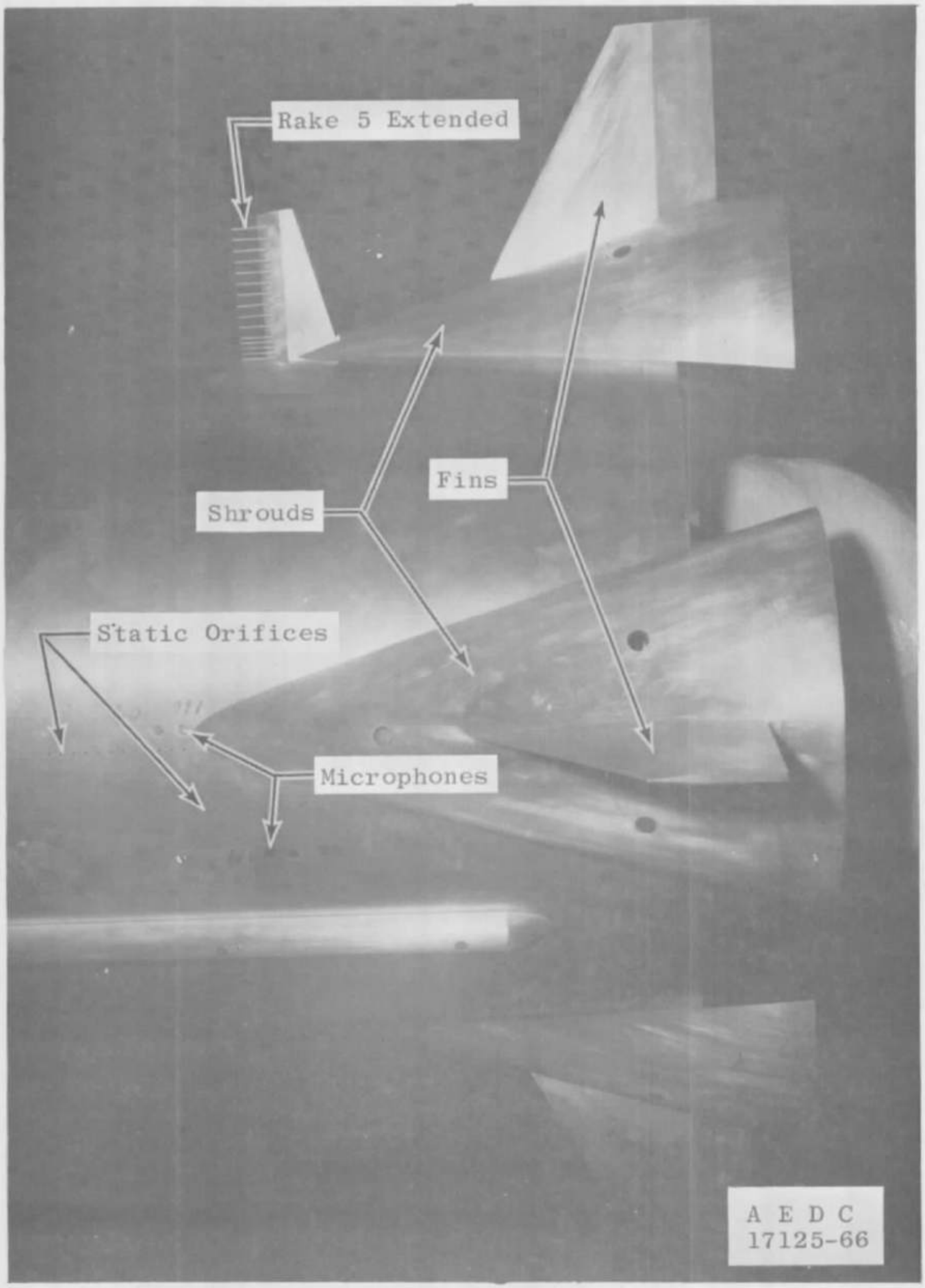


c. Model Nose
Fig. 2 Continued



d. S-IVB-S-II Interstage Region

Fig. 2 Continued



e. S-IC Stage – Aft End of Model
Fig. 2 Concluded

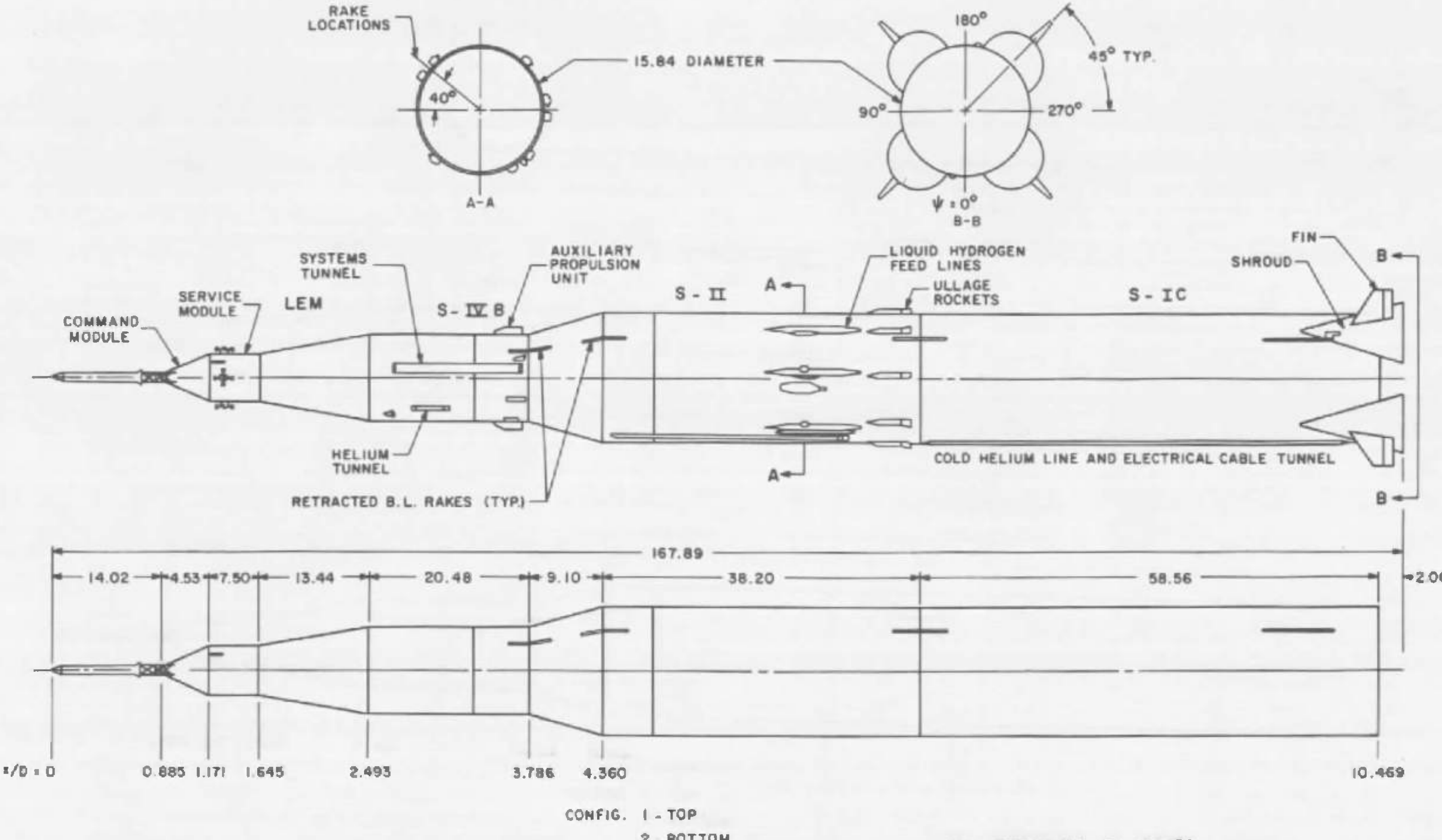
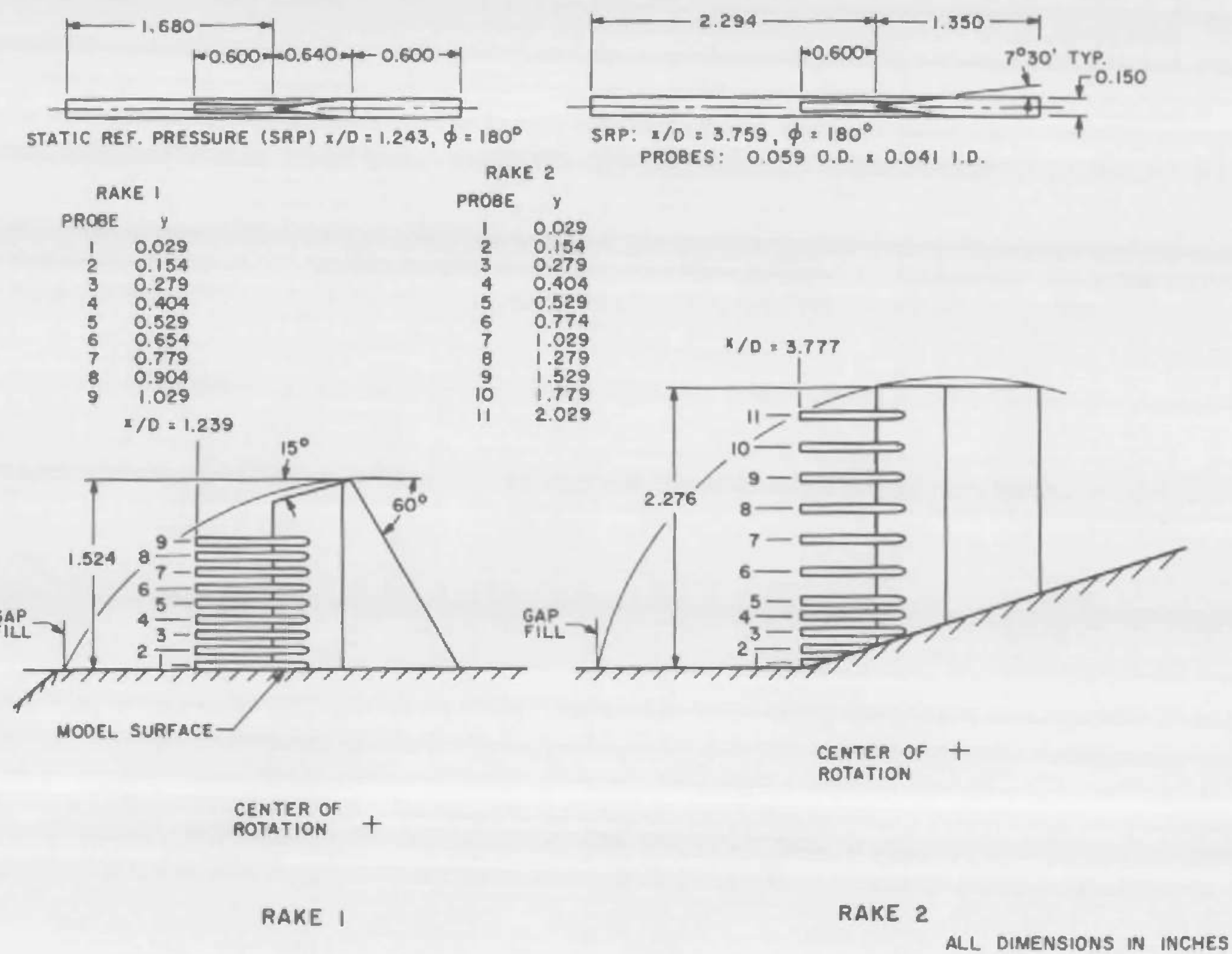


Fig. 3 Model Details



RAKE 1

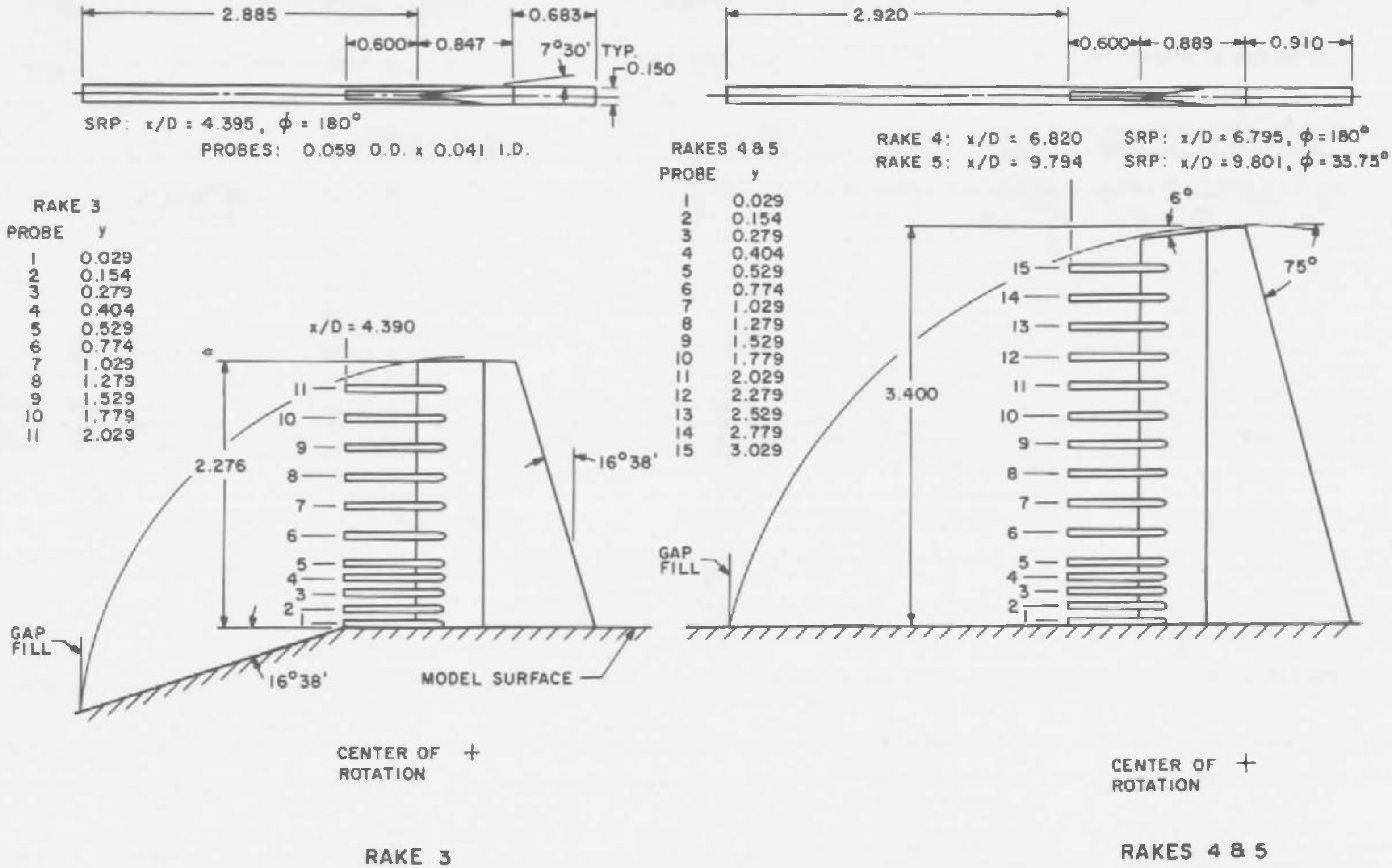
PROBE	y
1	0.029
2	0.154
3	0.279
4	0.404
5	0.529
6	0.654
7	0.779
8	0.904
9	1.029

RAKE 2

PROBE	y
1	0.029
2	0.154
3	0.279
4	0.404
5	0.529
6	0.774
7	1.029
8	1.279
9	1.529
10	1.779
11	2.029

a. Rakes 1 and 2

Fig. 4 Details of Boundary-Layer Rakes



RAKE 3

PROBE	y
1	0.029
2	0.154
3	0.279
4	0.404
5	0.529
6	0.774
7	1.029
8	1.279
9	1.529
10	1.779
11	2.029

RAKES 4 & 5

PROBE	y
1	0.029
2	0.154
3	0.279
4	0.404
5	0.529
6	0.774
7	1.029
8	1.279
9	1.529
10	1.779
11	2.029
12	2.279
13	2.529
14	2.779
15	3.029

ALL DIMENSIONS IN INCHES

b. Rakes 3, 4, and 5

Fig. 4 Concluded

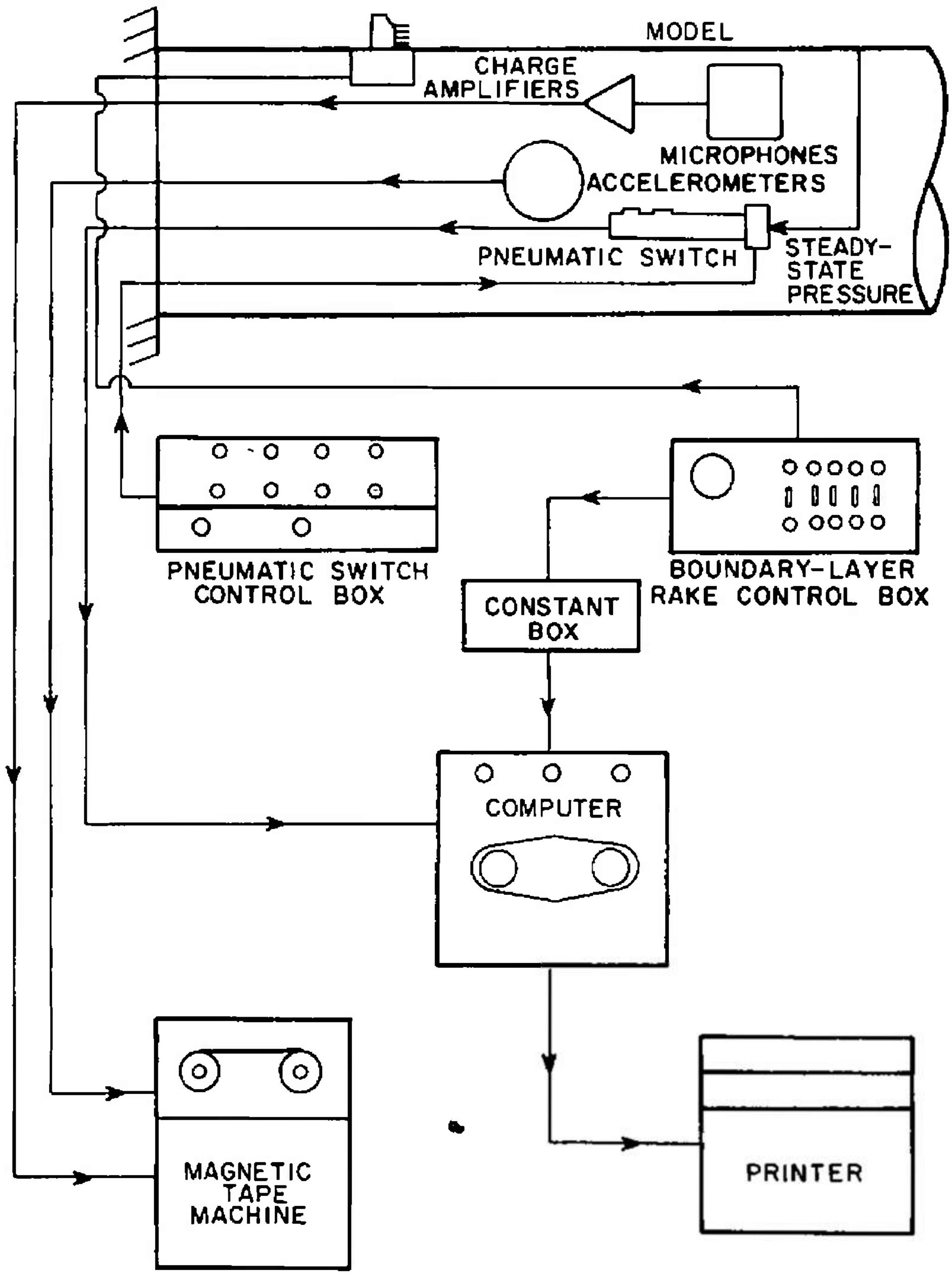


Fig. 5 Instrumentation Arrangement

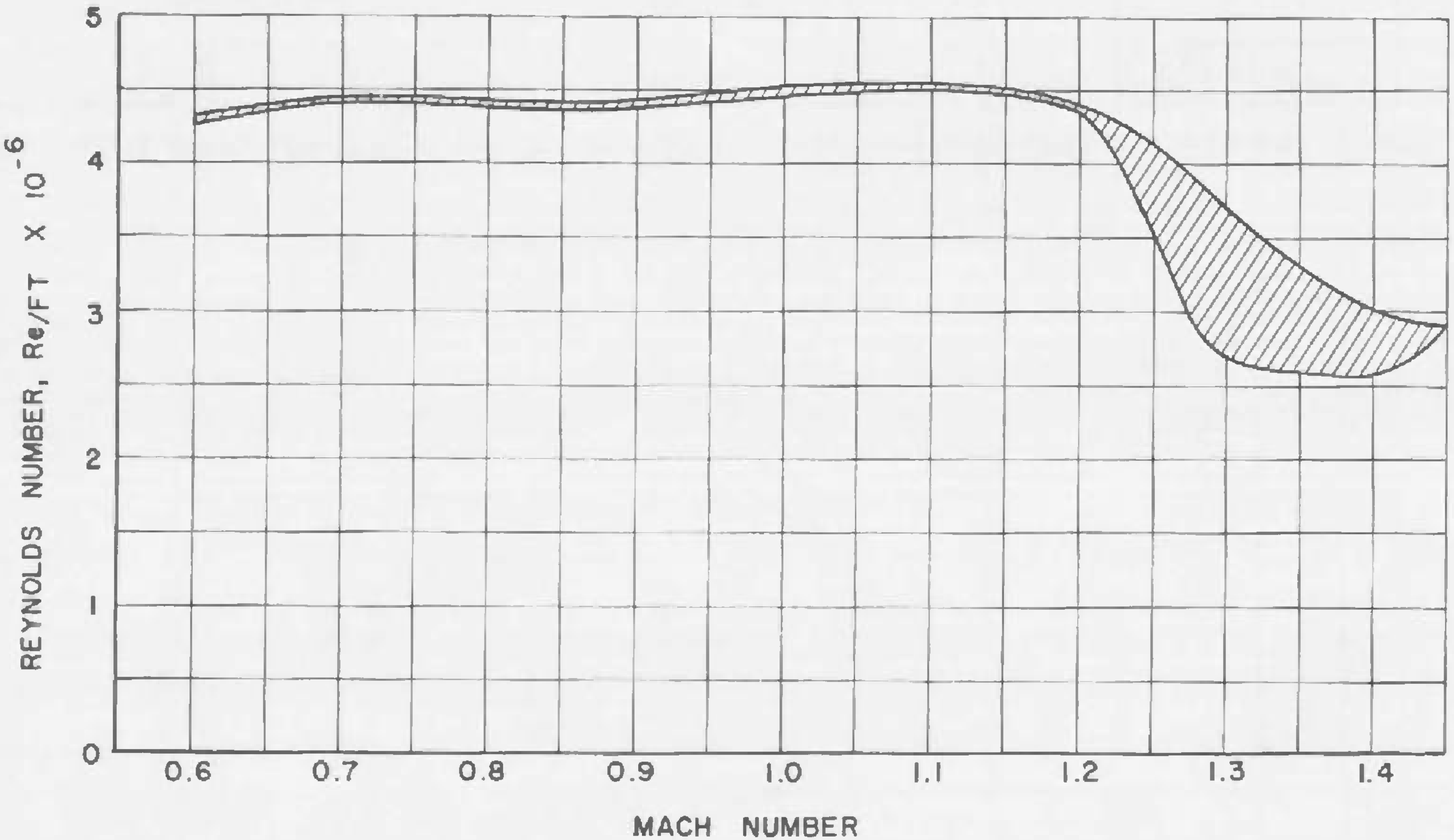
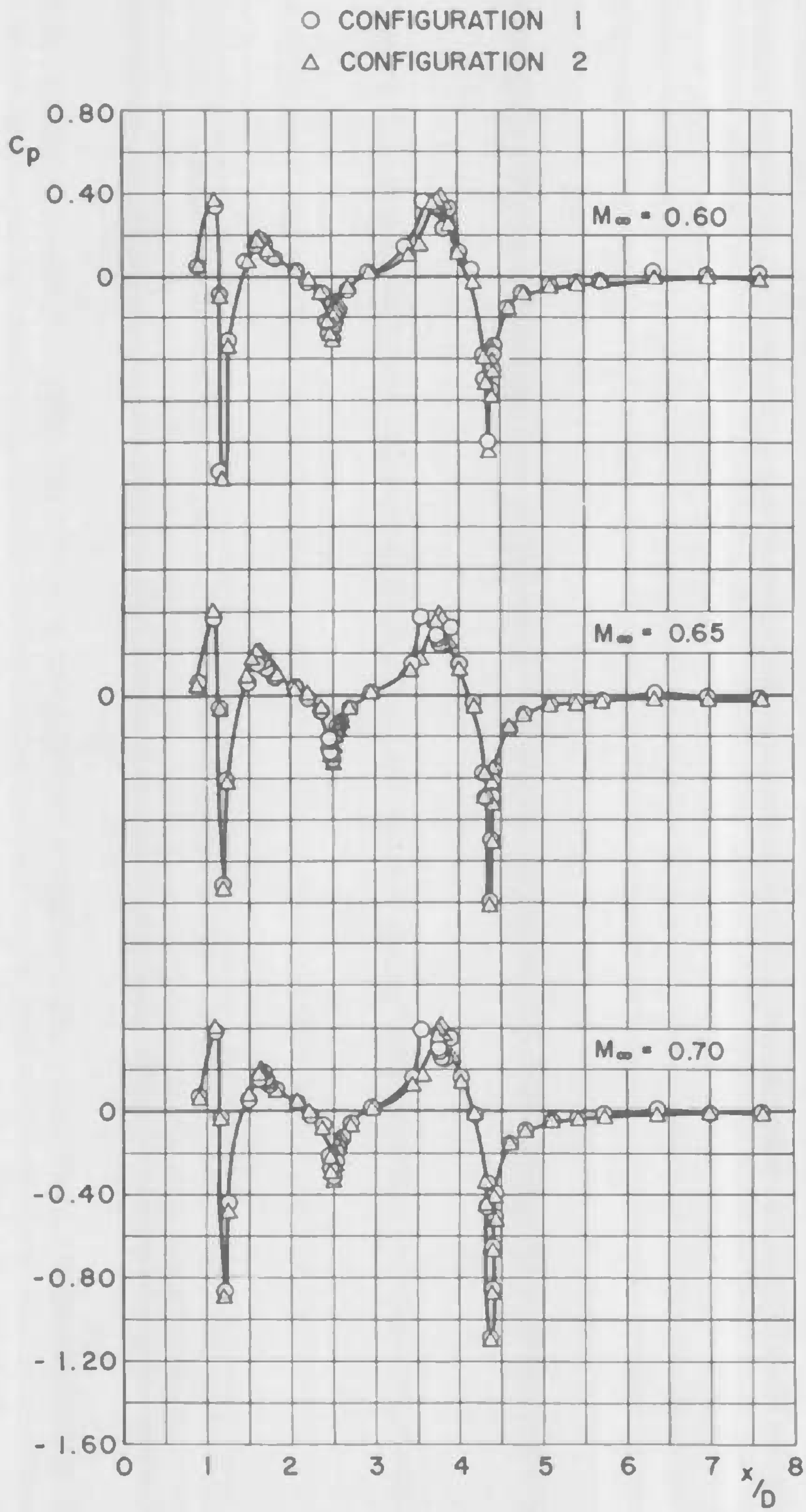
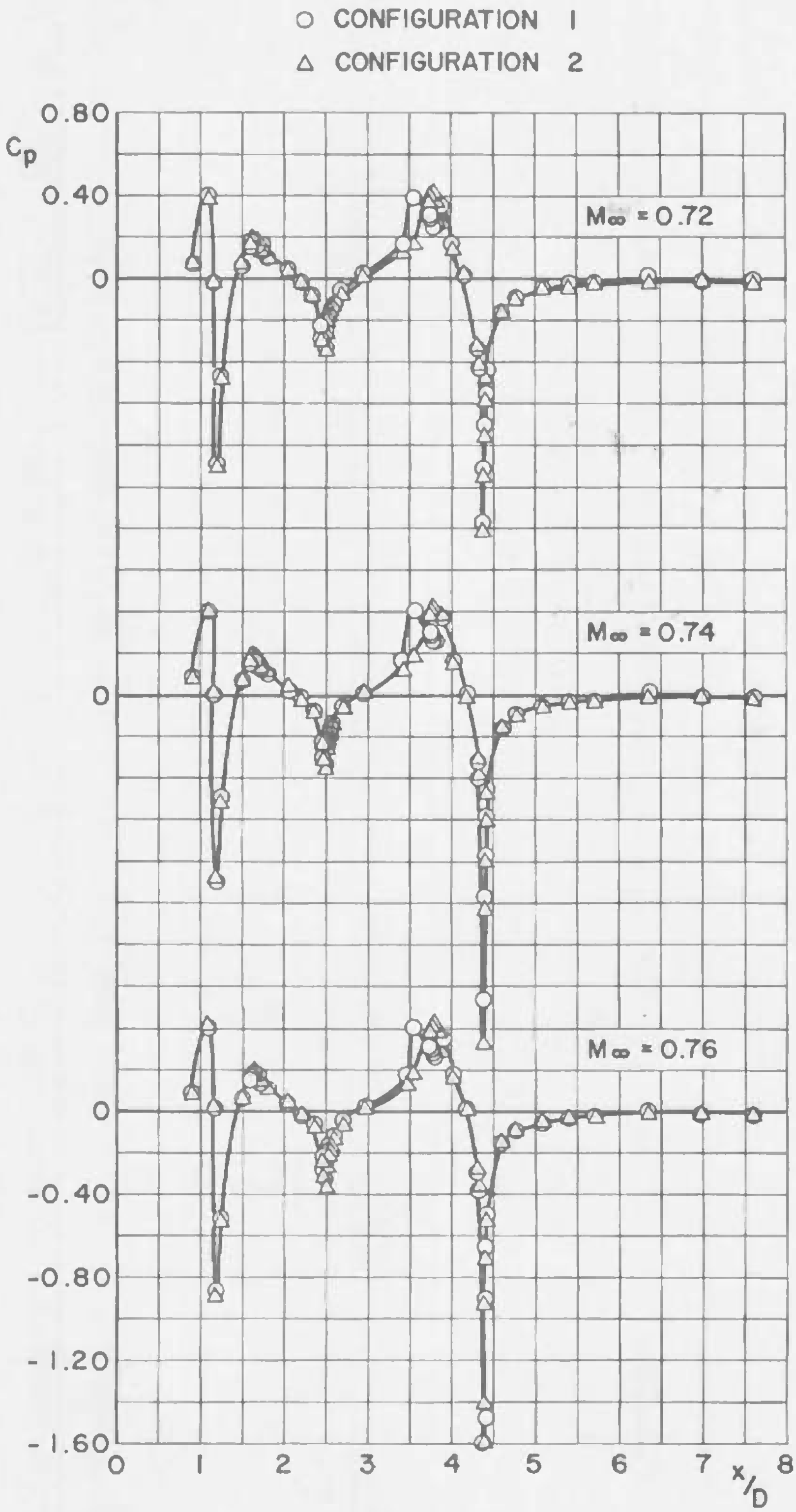


Fig. 6 Variation of Reynolds Number with Mach Number



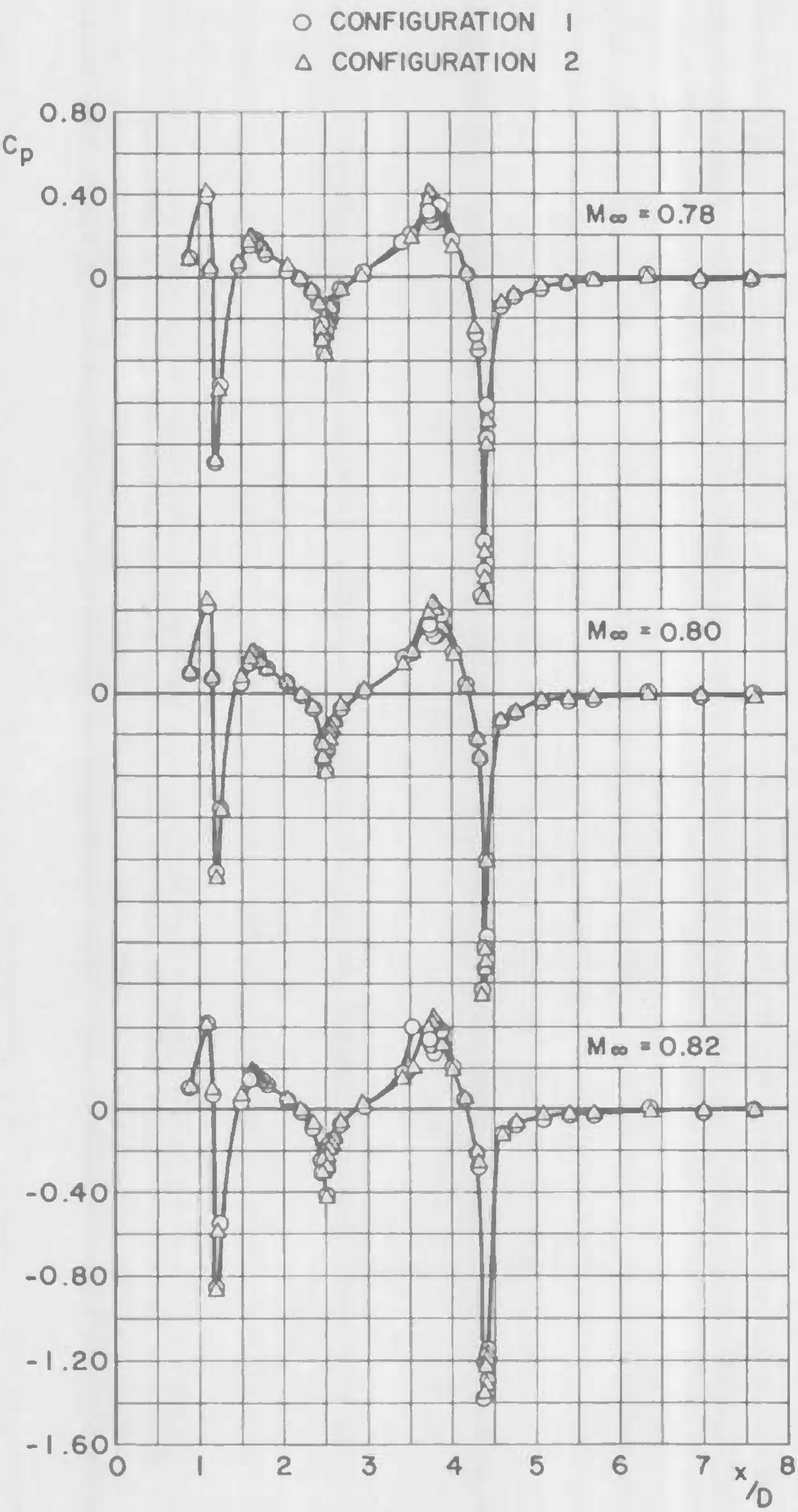
a. M_∞ = 0.60 through 0.70

Fig. 7 Variation of Pressure Coefficients along Model



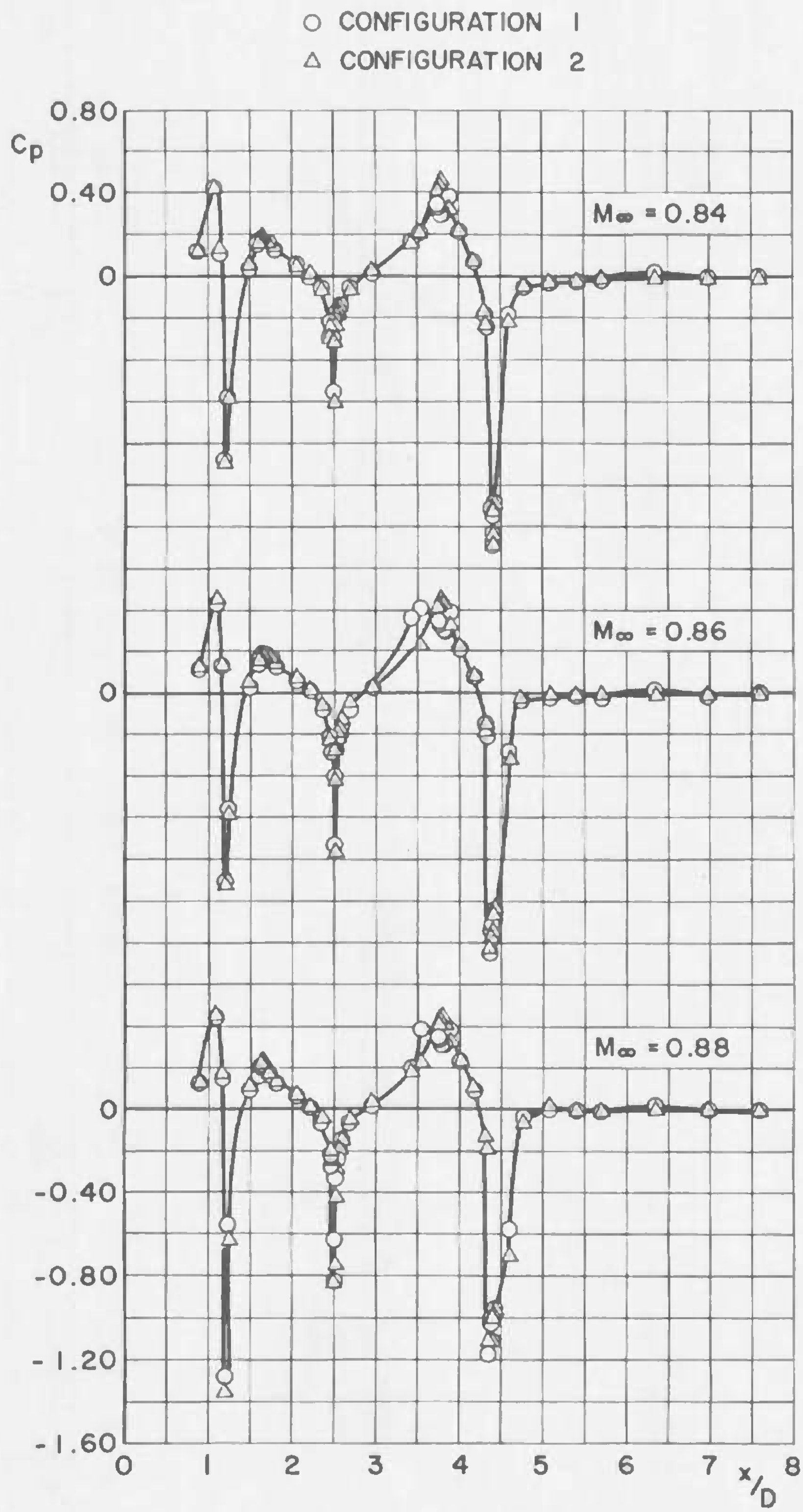
b. M_∞ = 0.72 through 0.76

Fig. 7 Continued



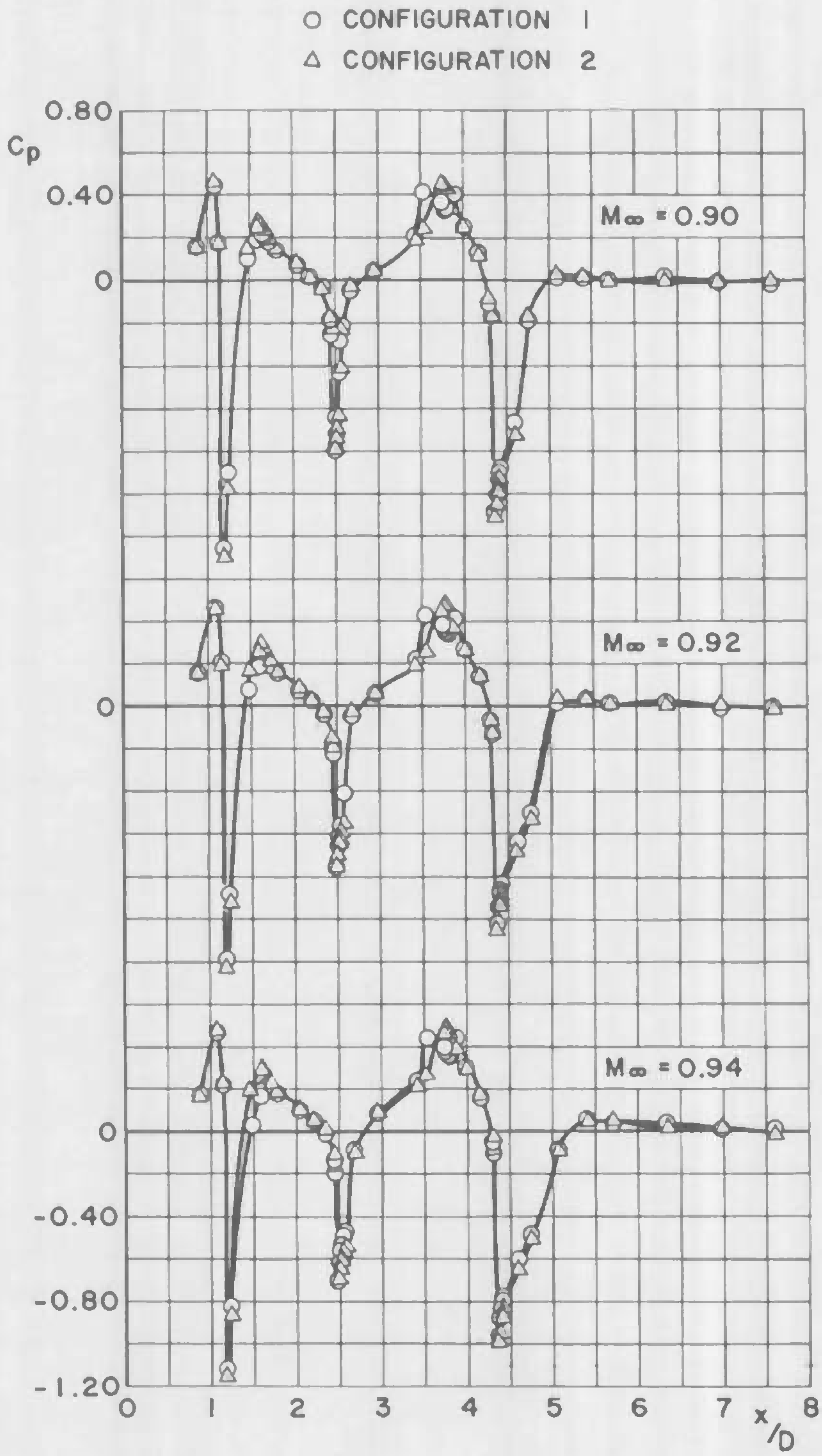
c. M_∞ = 0.78 through 0.82

Fig. 7 Continued



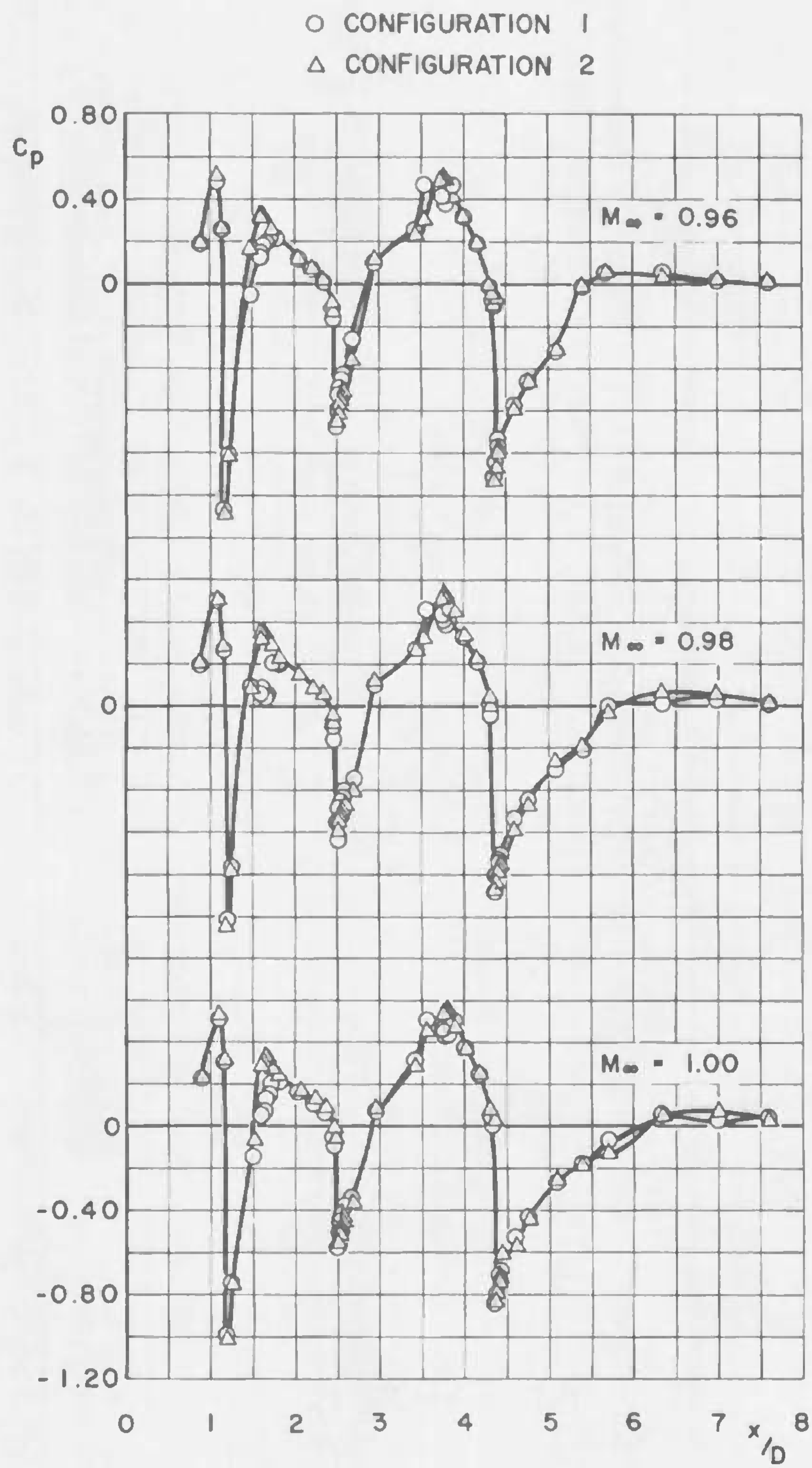
d. M_∞ = 0.84 through 0.88

Fig. 7 Continued



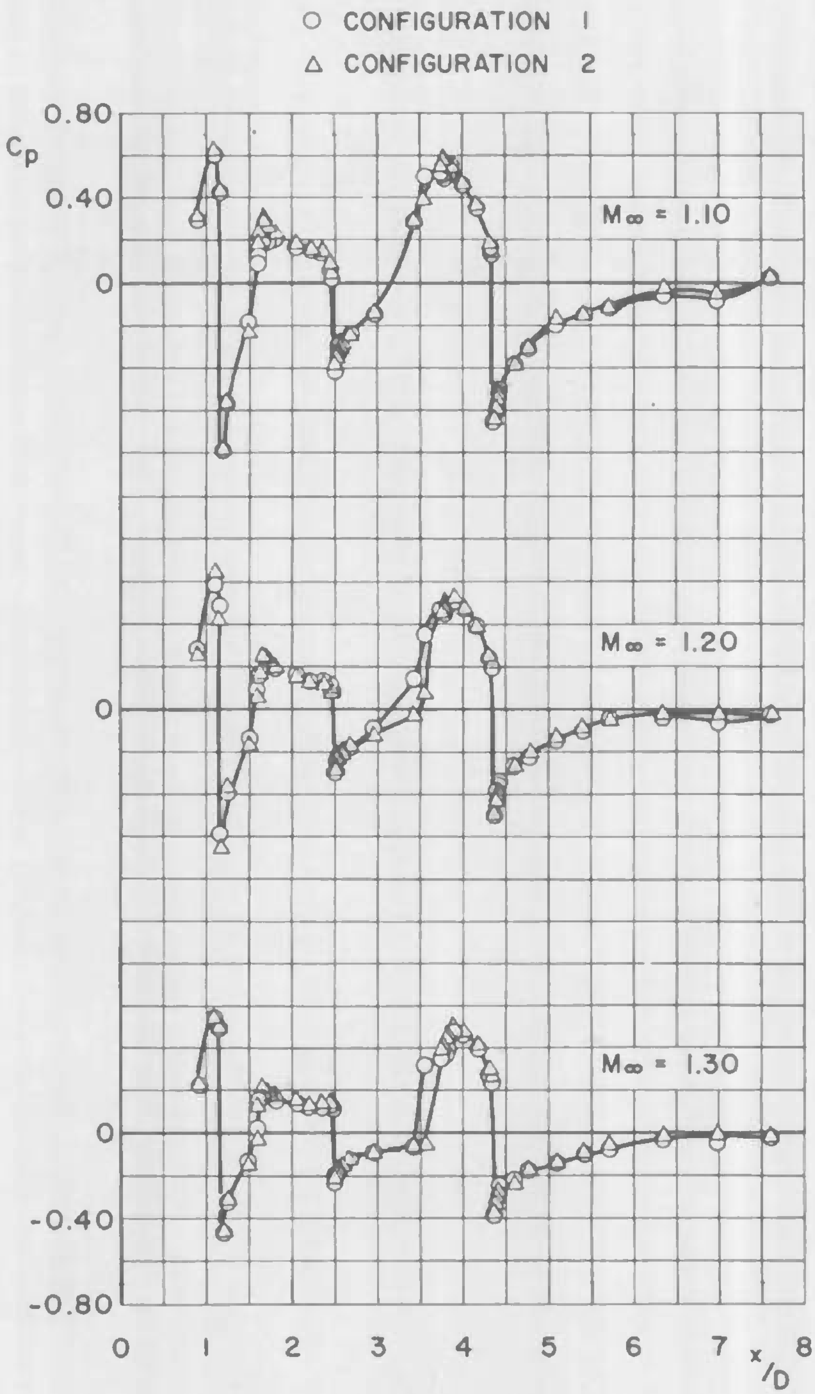
e. M_∞ = 0.90 through 0.94

Fig. 7 Continued



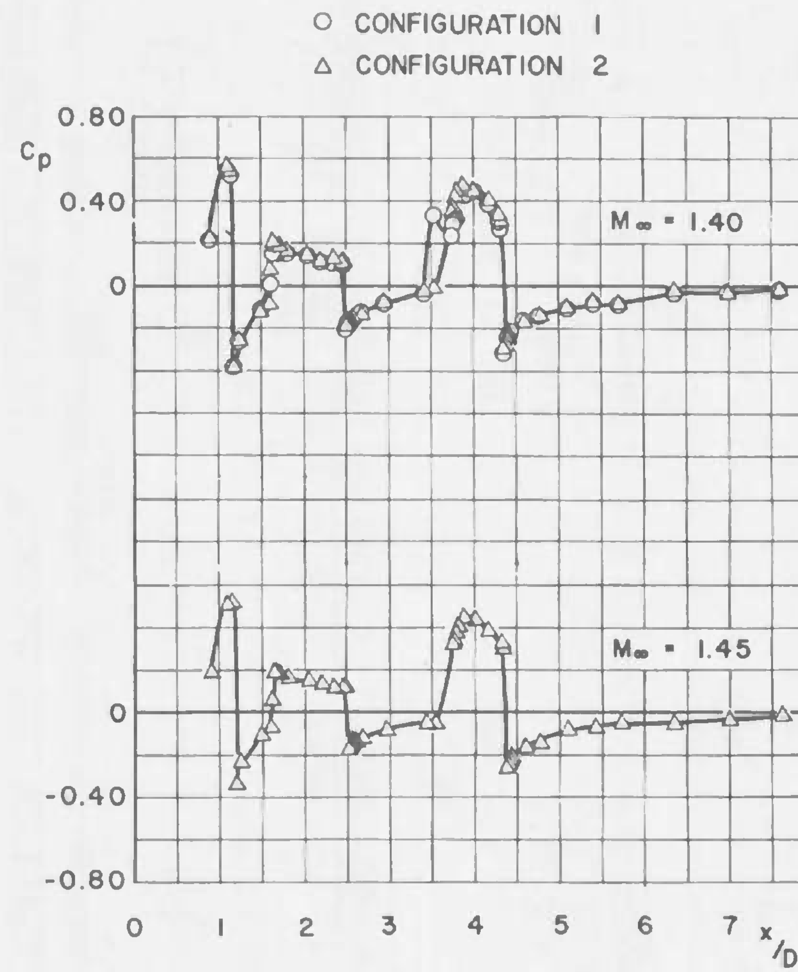
f. M_∞ = 0.96 through 1.00

Fig. 7 Continued



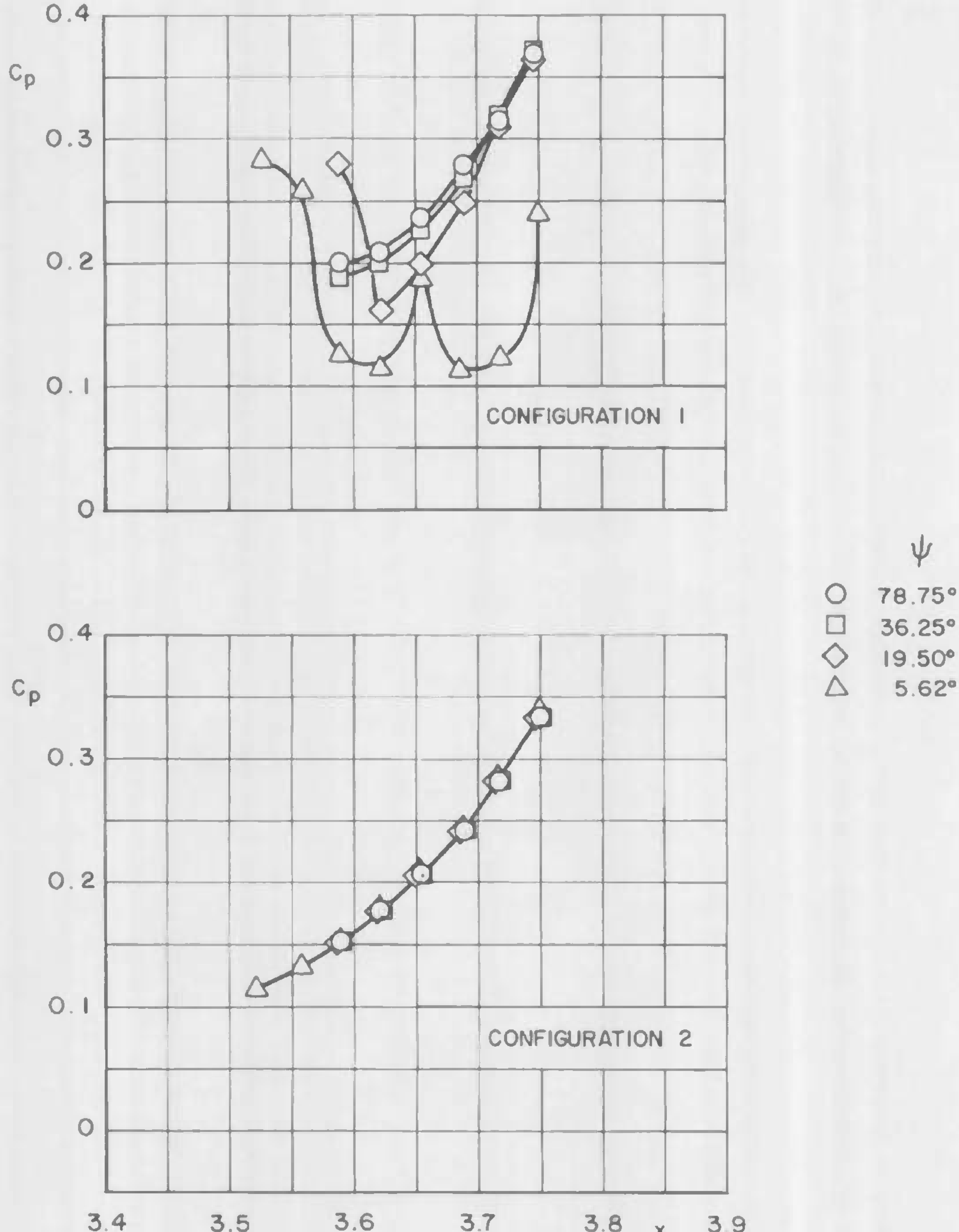
g. M_∞ = 1.10 through 1.30

Fig. 7 Continued



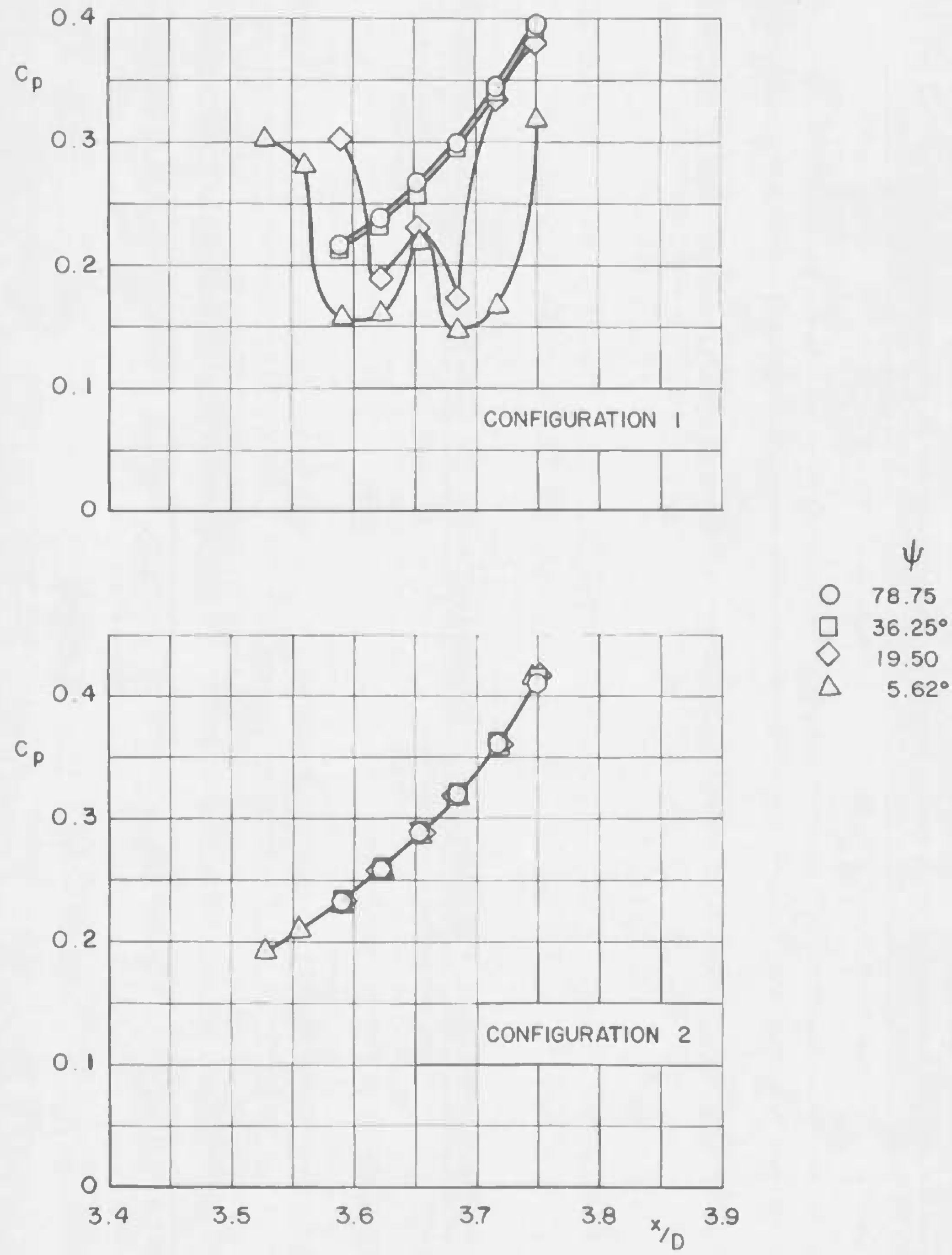
h. M_∞ = 1.40 and 1.45

Fig. 7 Concluded



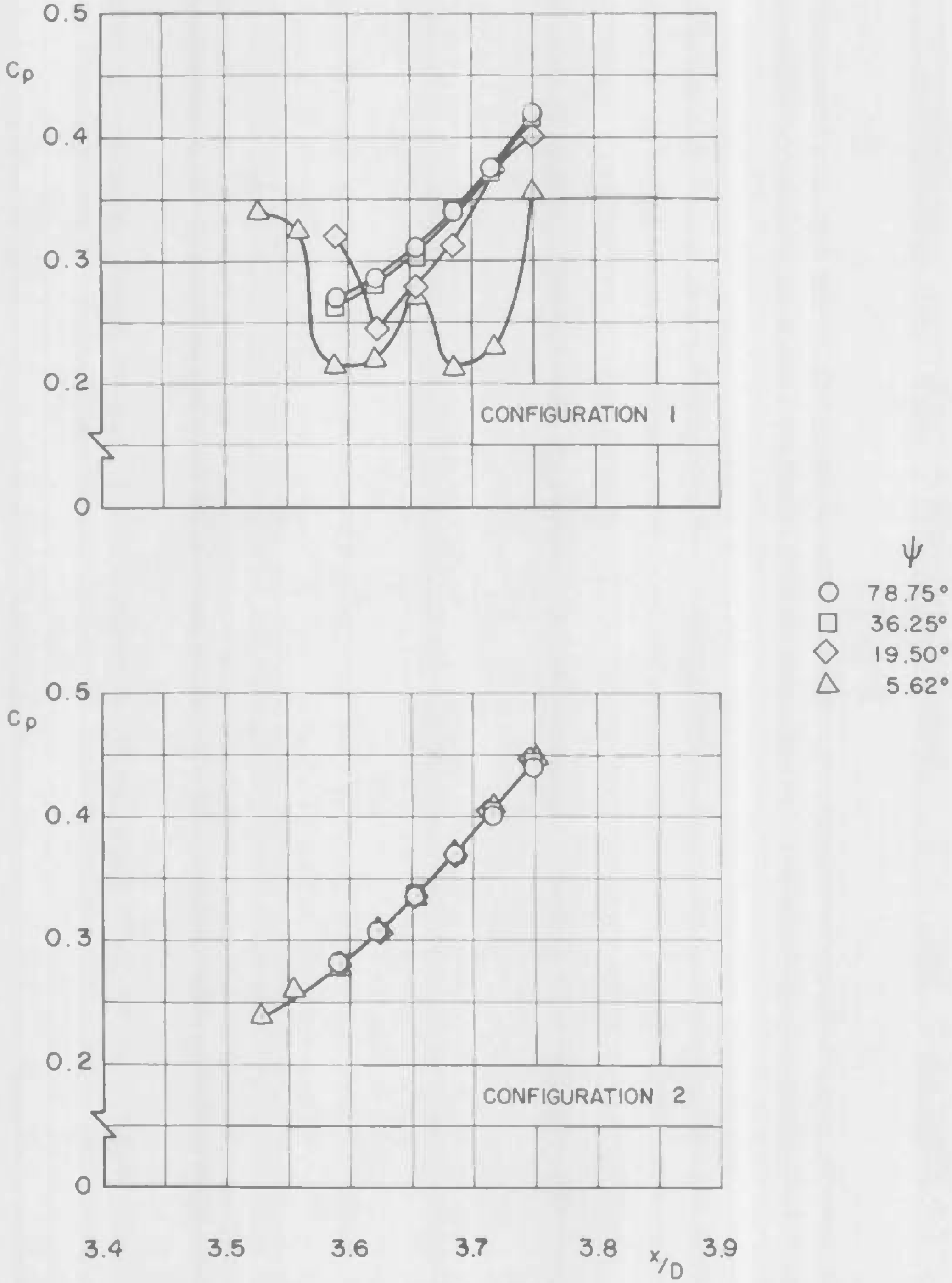
a. $M_\infty = 0.70$

Fig. 8 Protuberance and Interstage Effects on the Pressure Coefficients in the S-IVB Flare Region



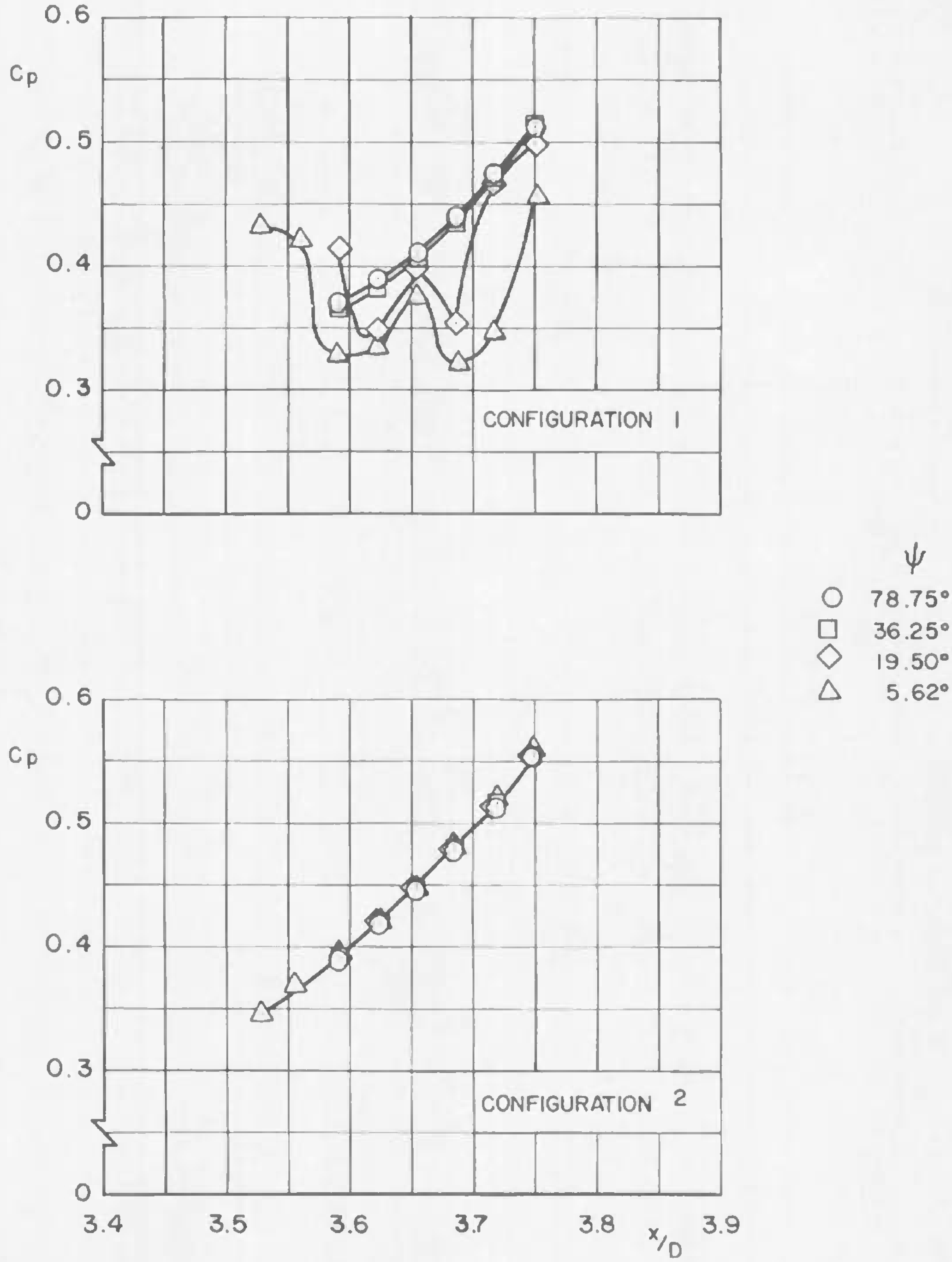
b. $M_\infty = 0.80$

Fig. 8 Continued



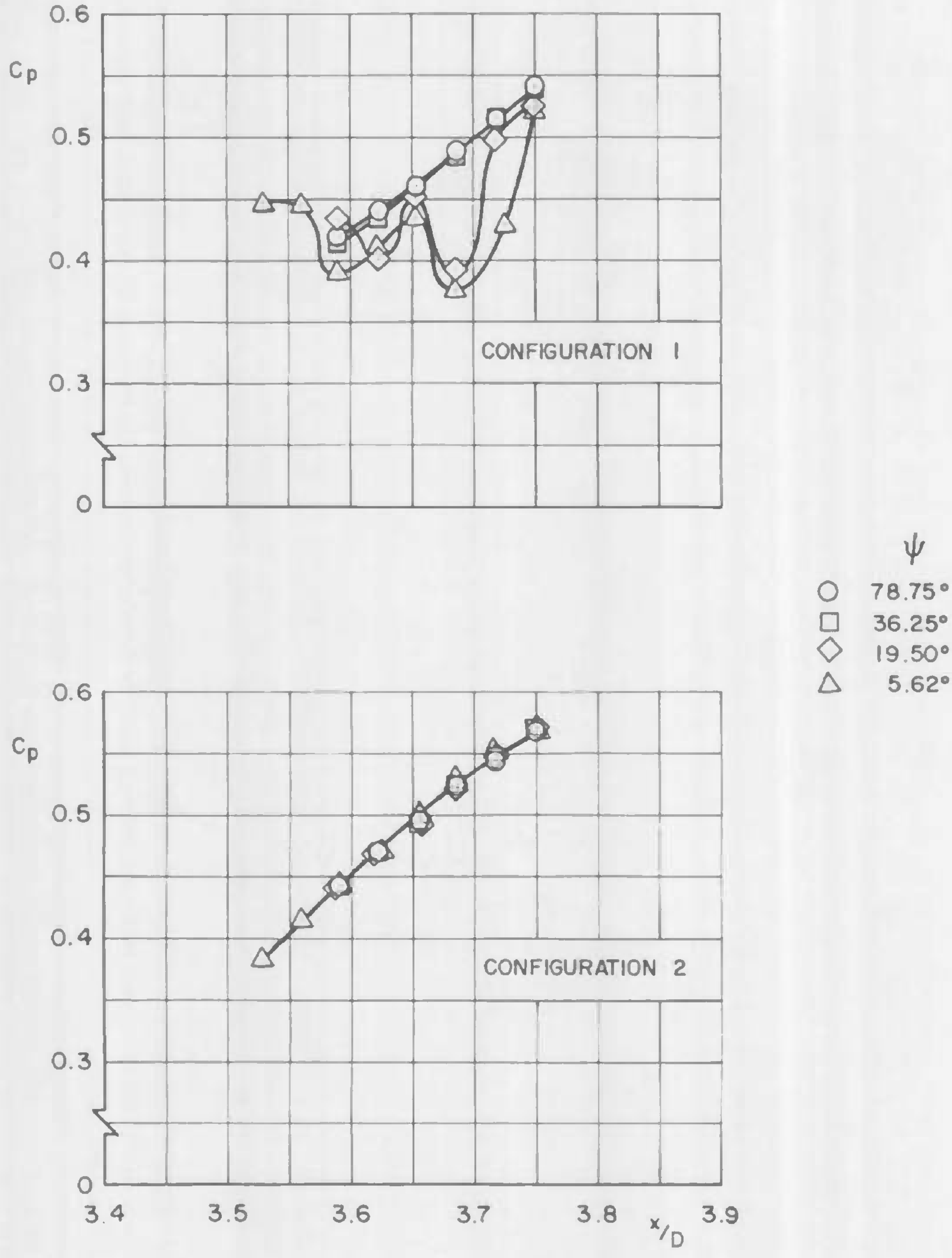
c. M_∞ = 0.90

Fig. 8 Continued



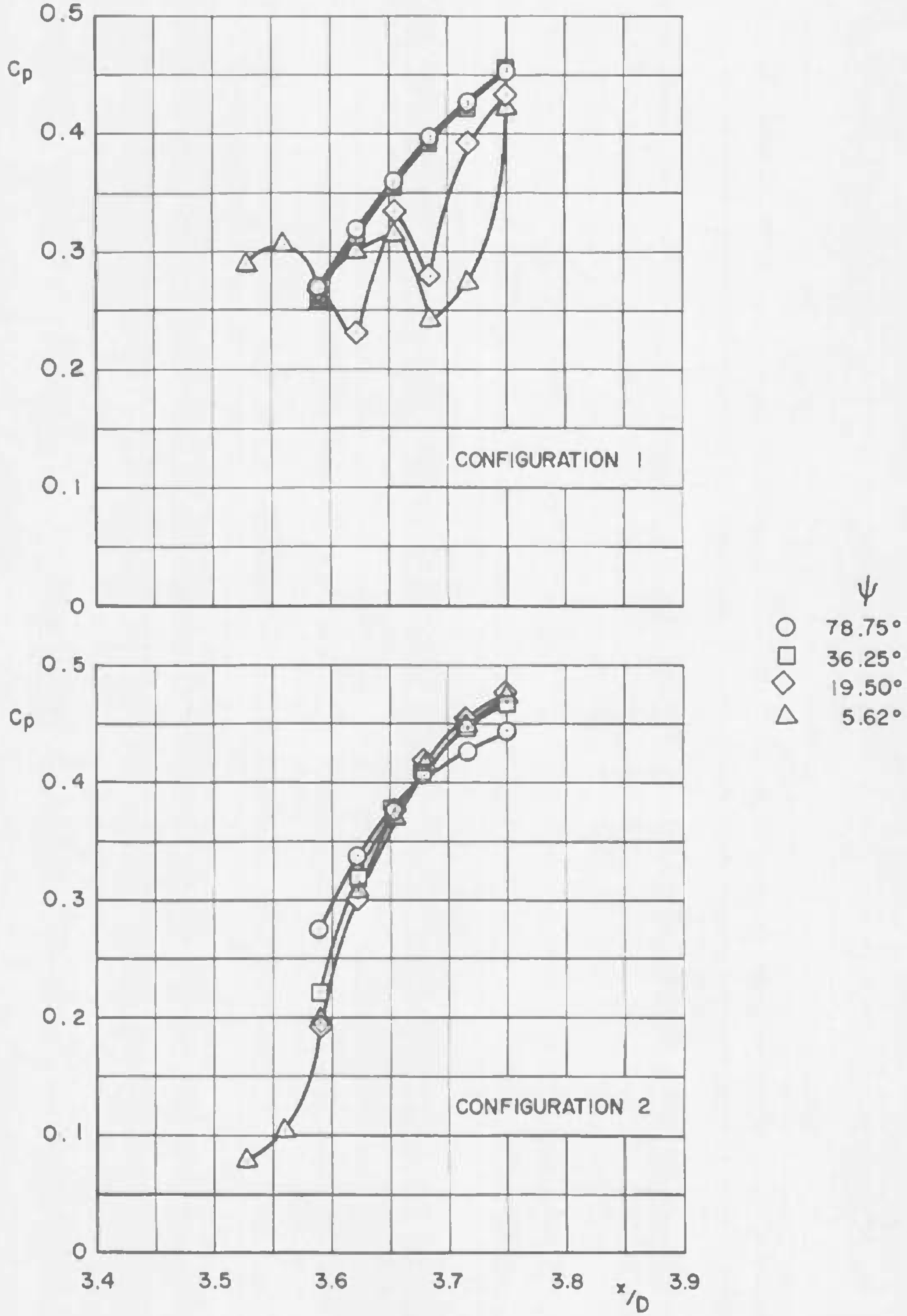
d. $M_\infty = 1.00$

Fig. 8 Continued



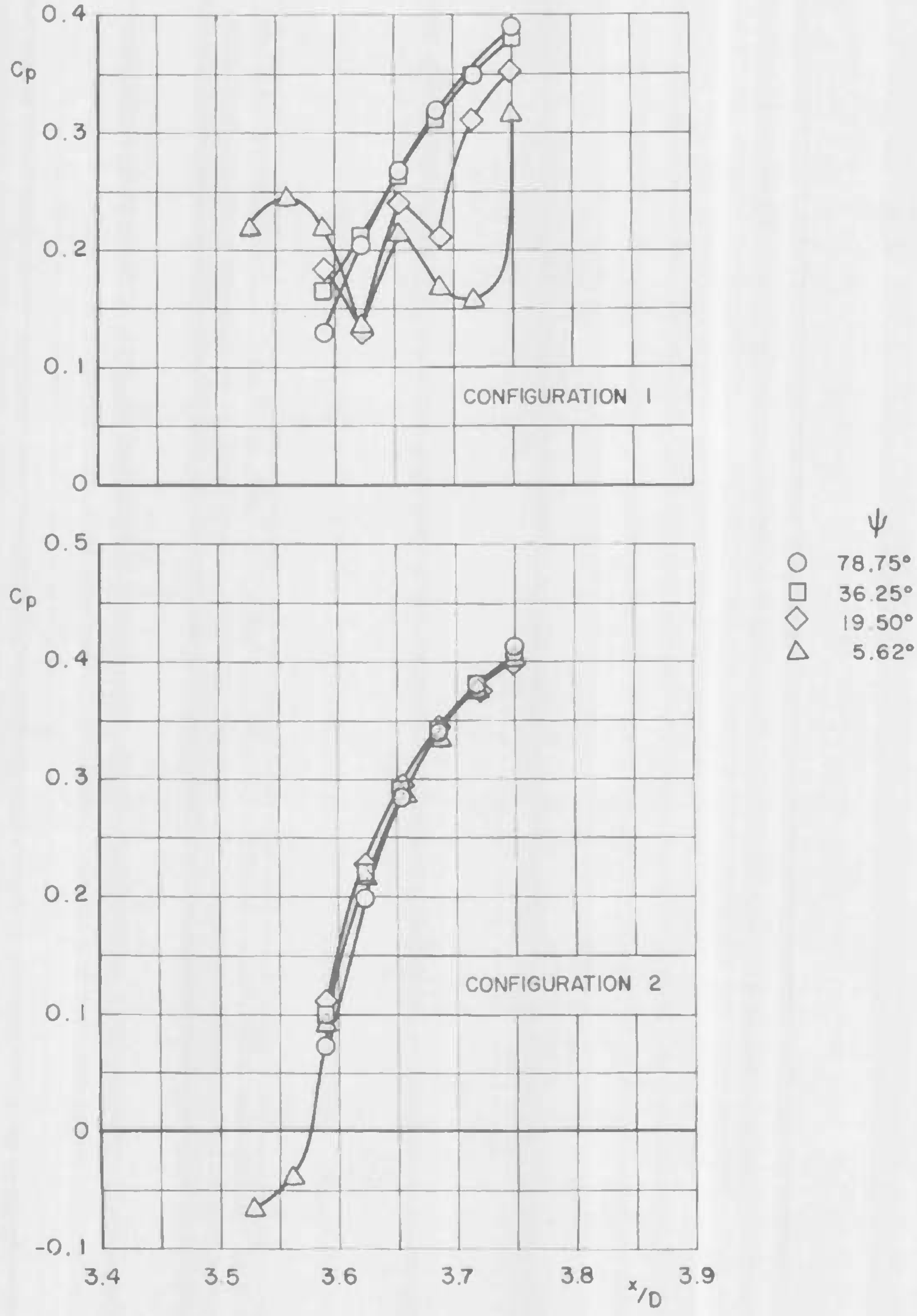
e. $M_\infty = 1.10$

Fig. 8 Continued



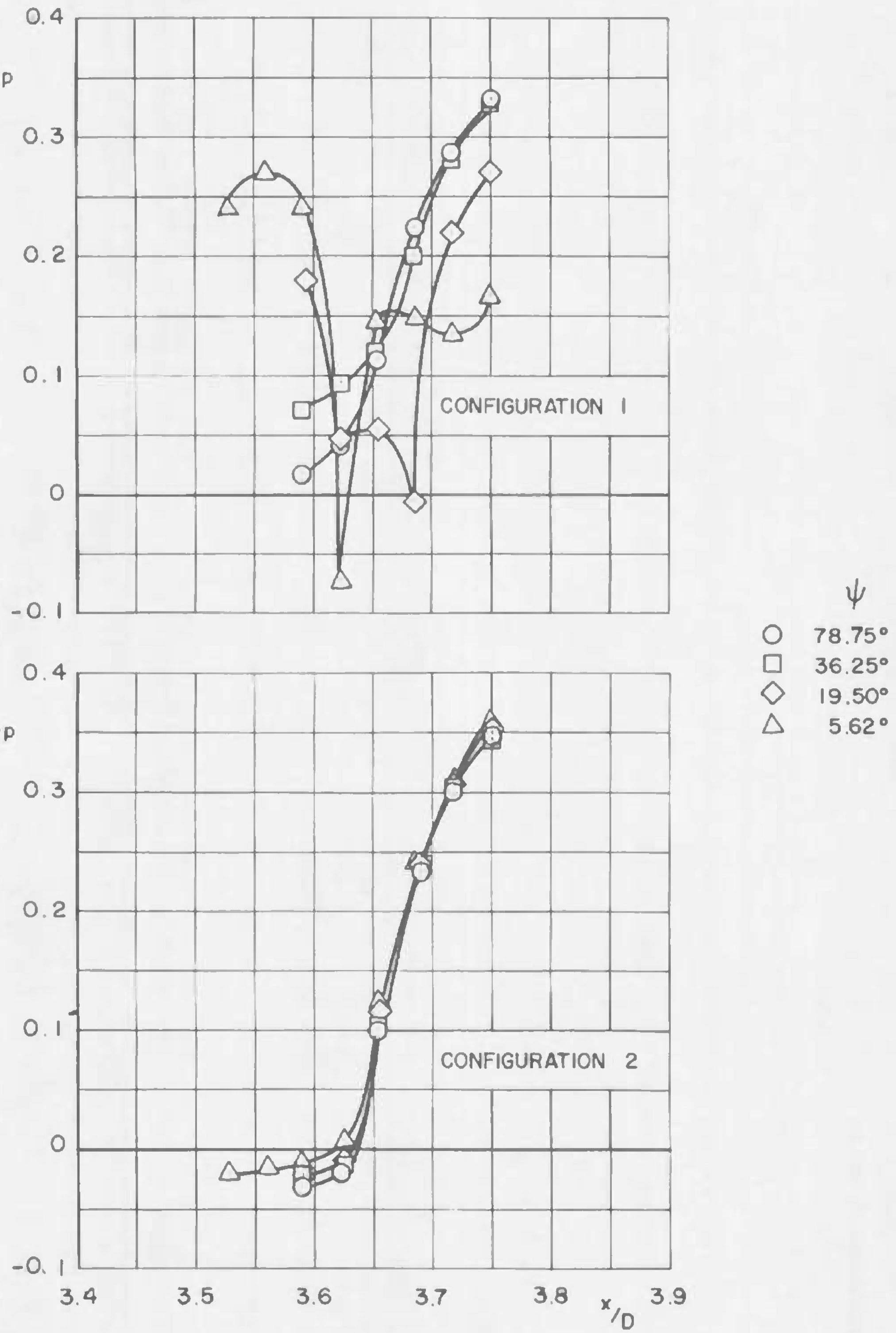
f. $M_\infty = 1.20$

Fig. 8 Continued



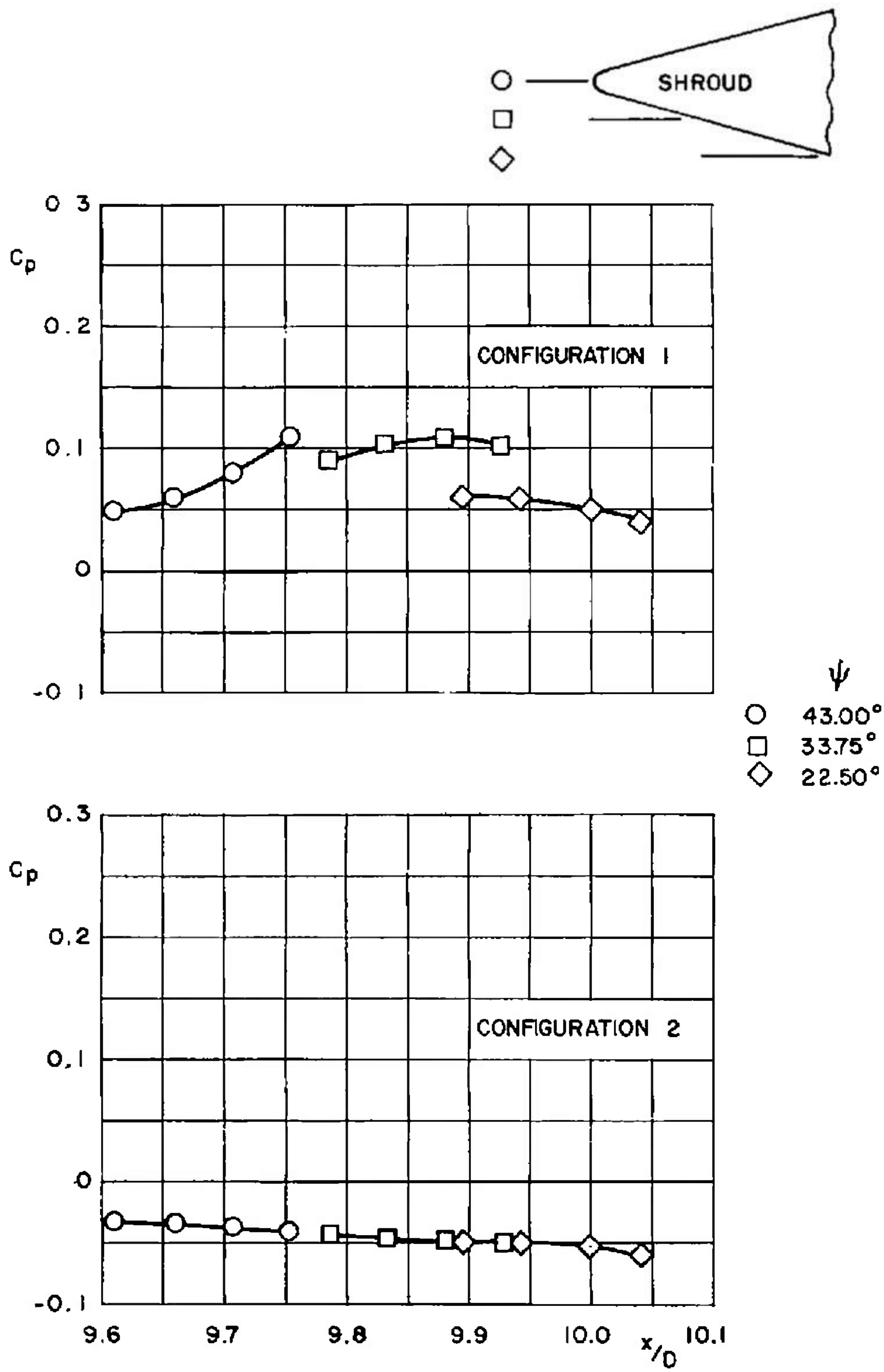
g. $M_\infty = 1.30$

Fig. 8 Continued



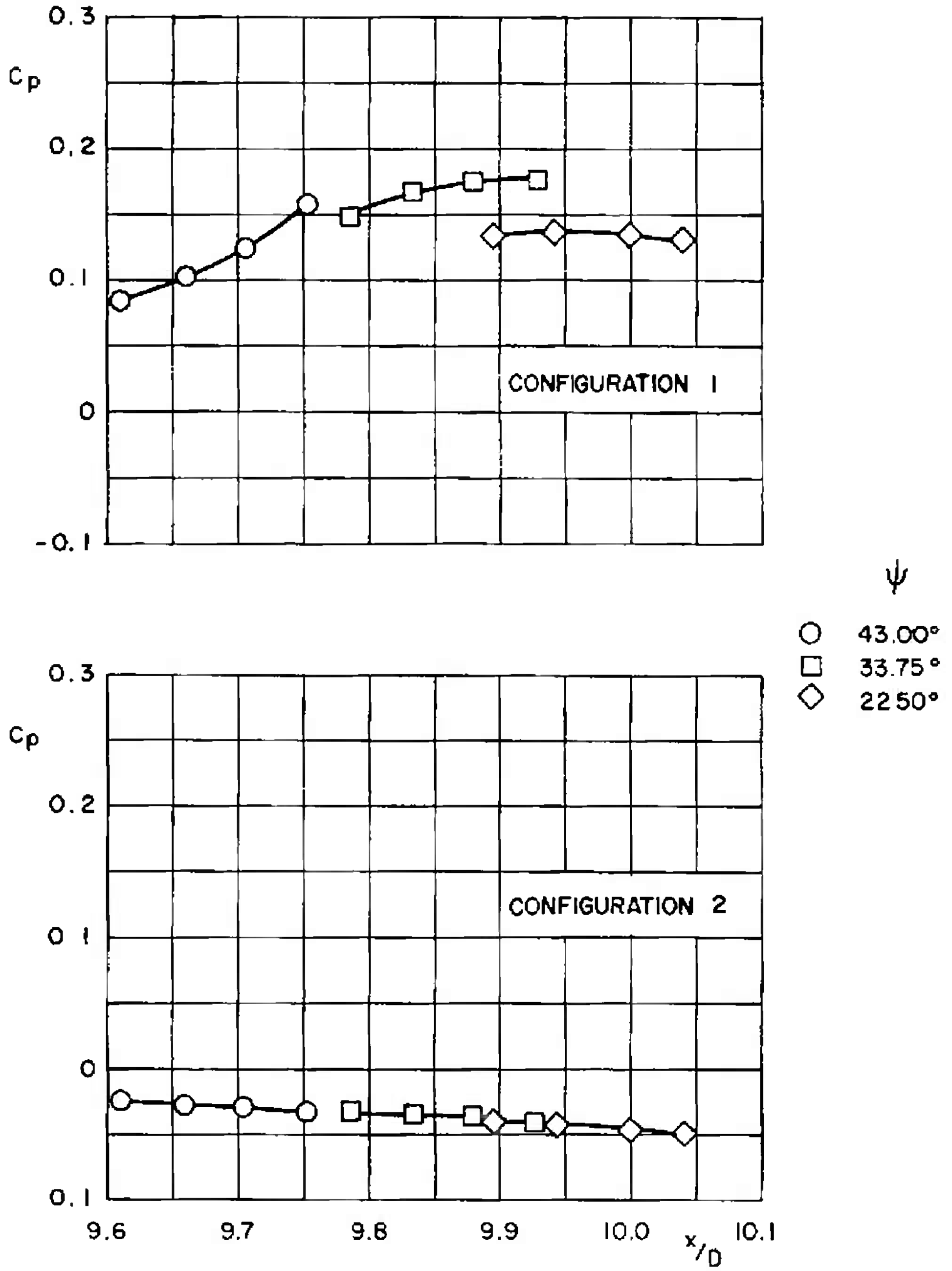
h. $M_\infty = 1.40$

Fig. 8 Concluded



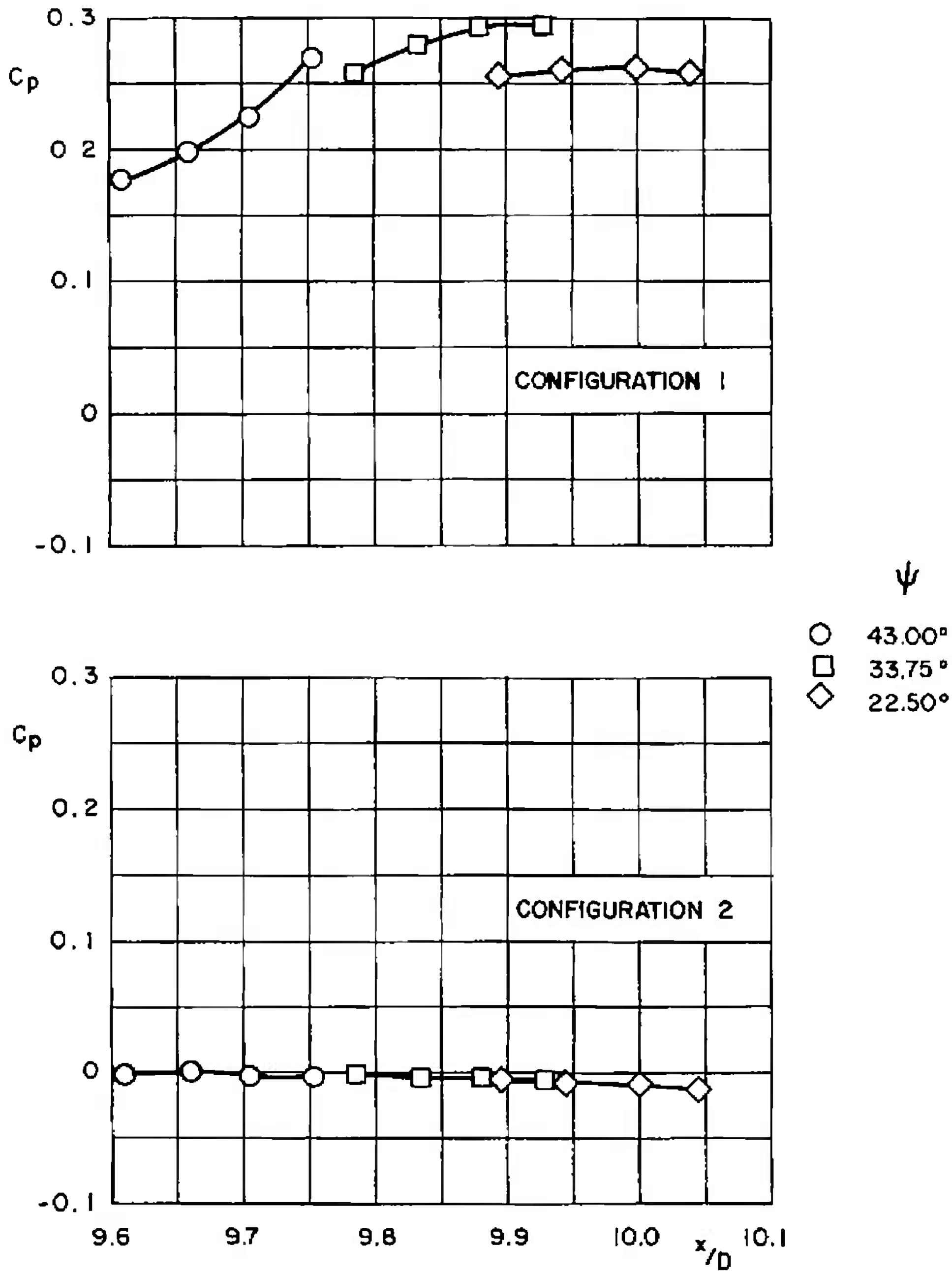
a. $M_\infty = 0.60$

Fig. 9 Shroud Effects on Local Pressure Coefficients



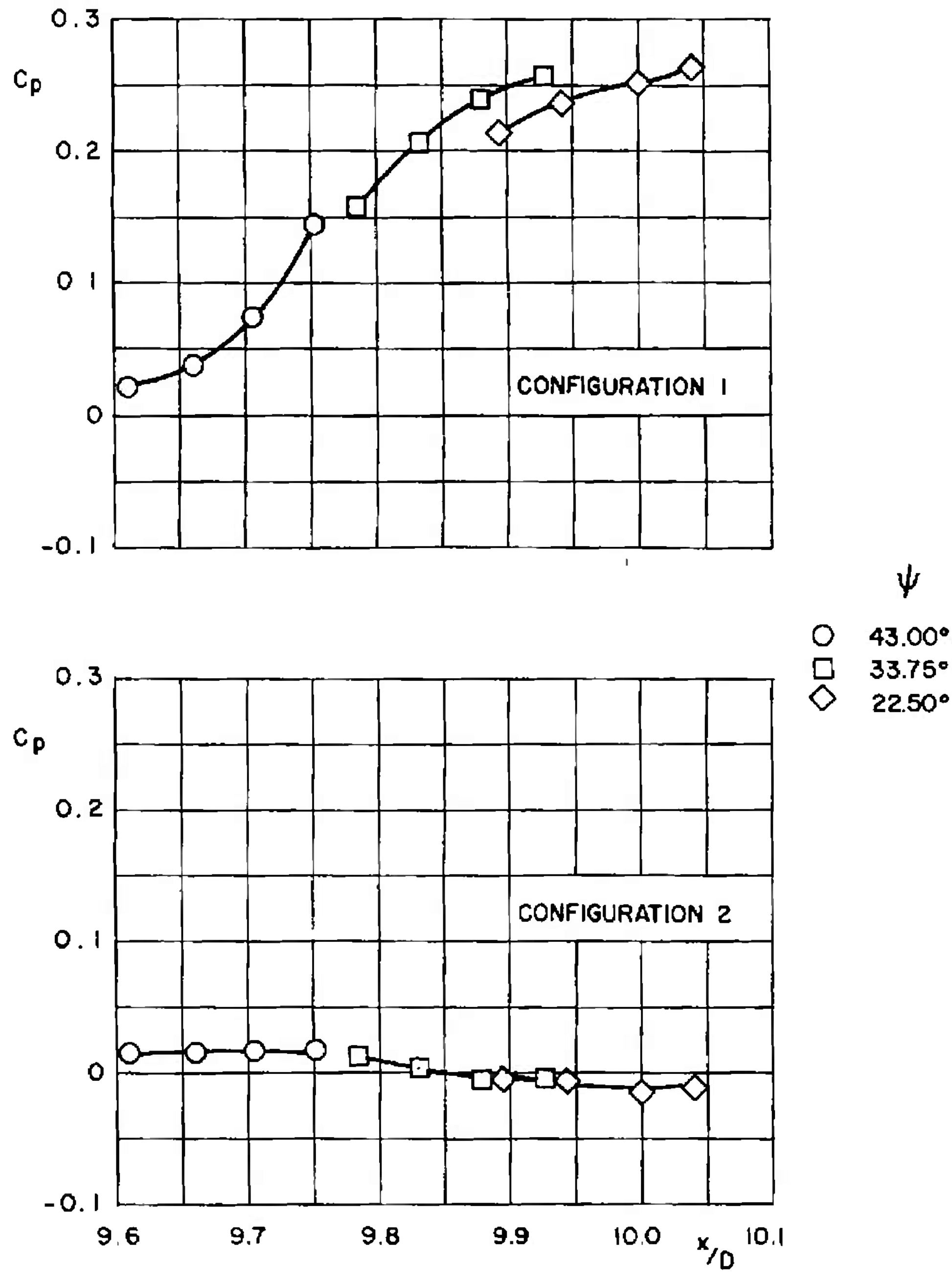
b. $M_\infty = 0.80$

Fig. 9 Continued



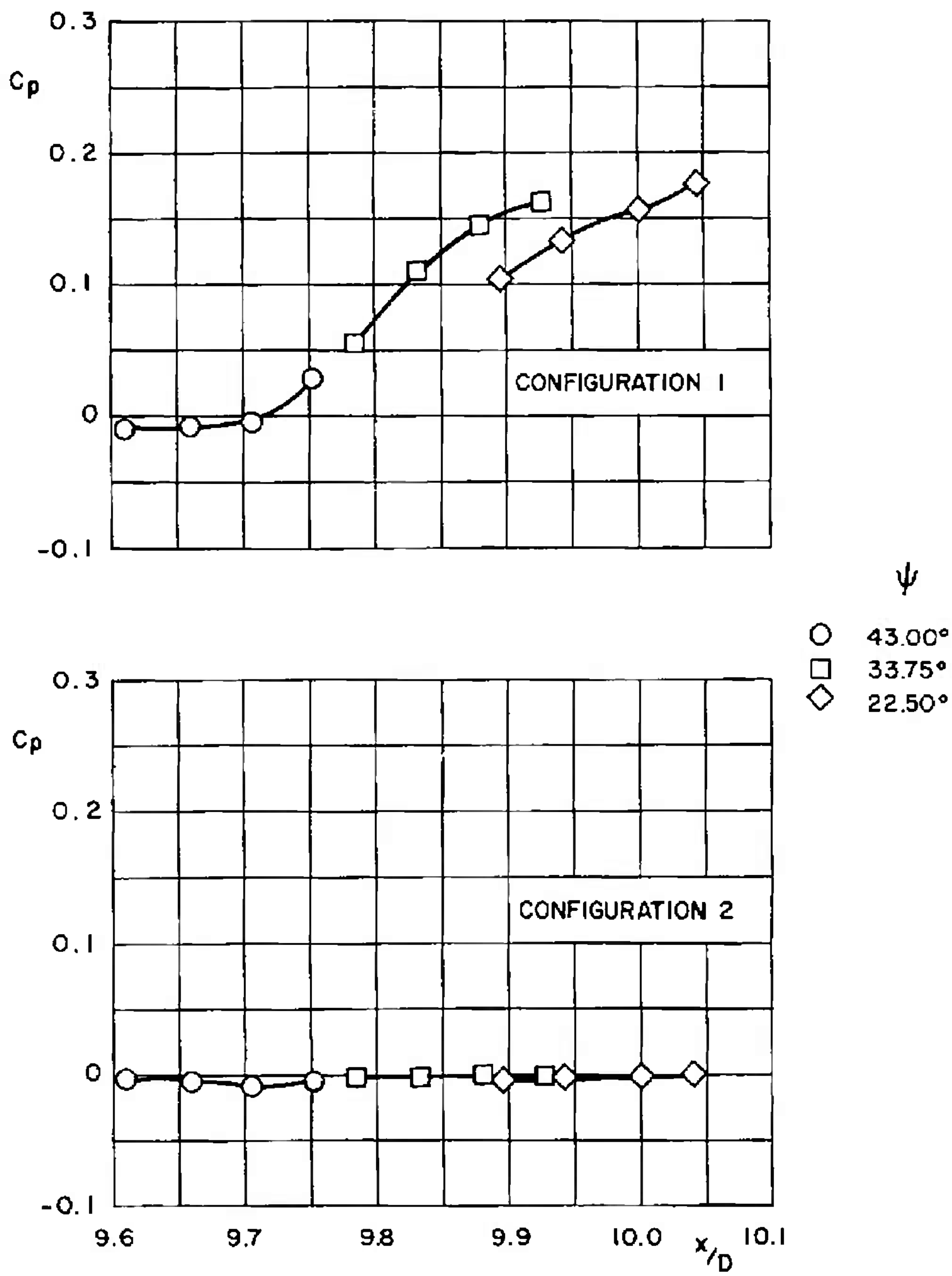
c. M_∞ = 1.00

Fig. 9 Continued



d. M_∞ = 1.20

Fig. 9 Continued



e. $M_\infty = 1.40$

Fig. 9 Concluded

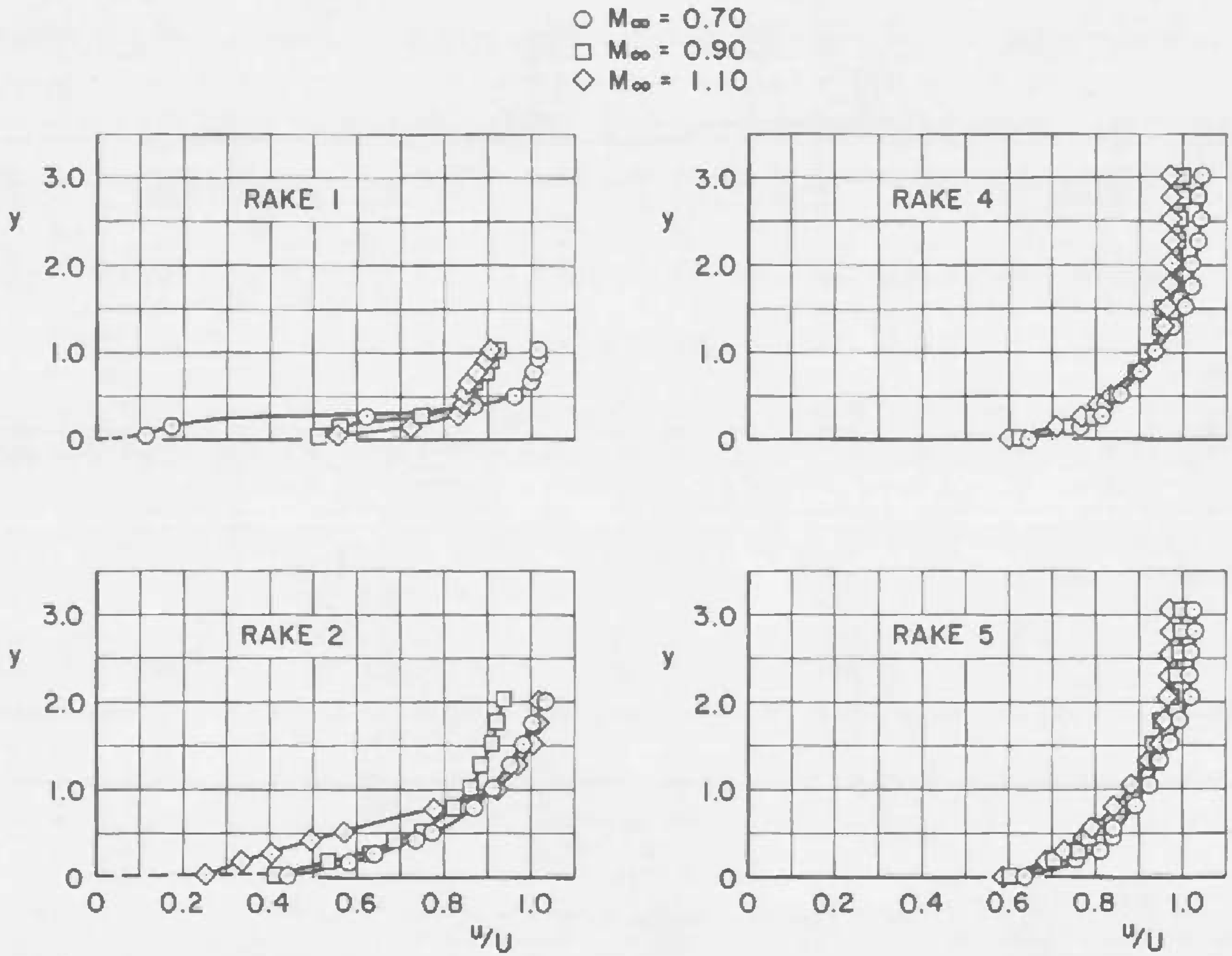


Fig. 10 Effect of Mach Number Change on Boundary-Layer Profile, Configuration 2

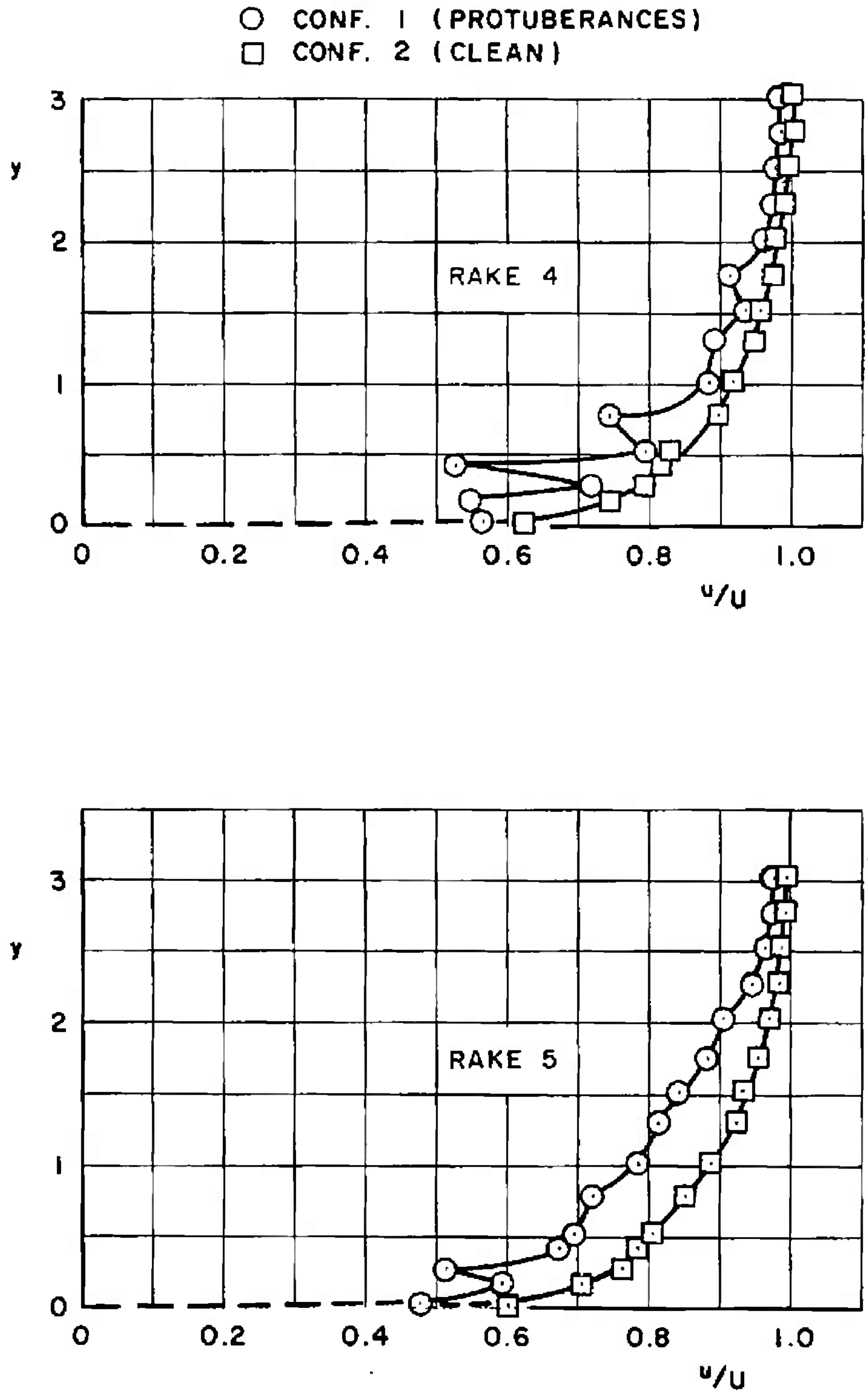


Fig. 11 Effect of Local Protuberances on Boundary-Layer Profiles, $M_\infty = 0.90$

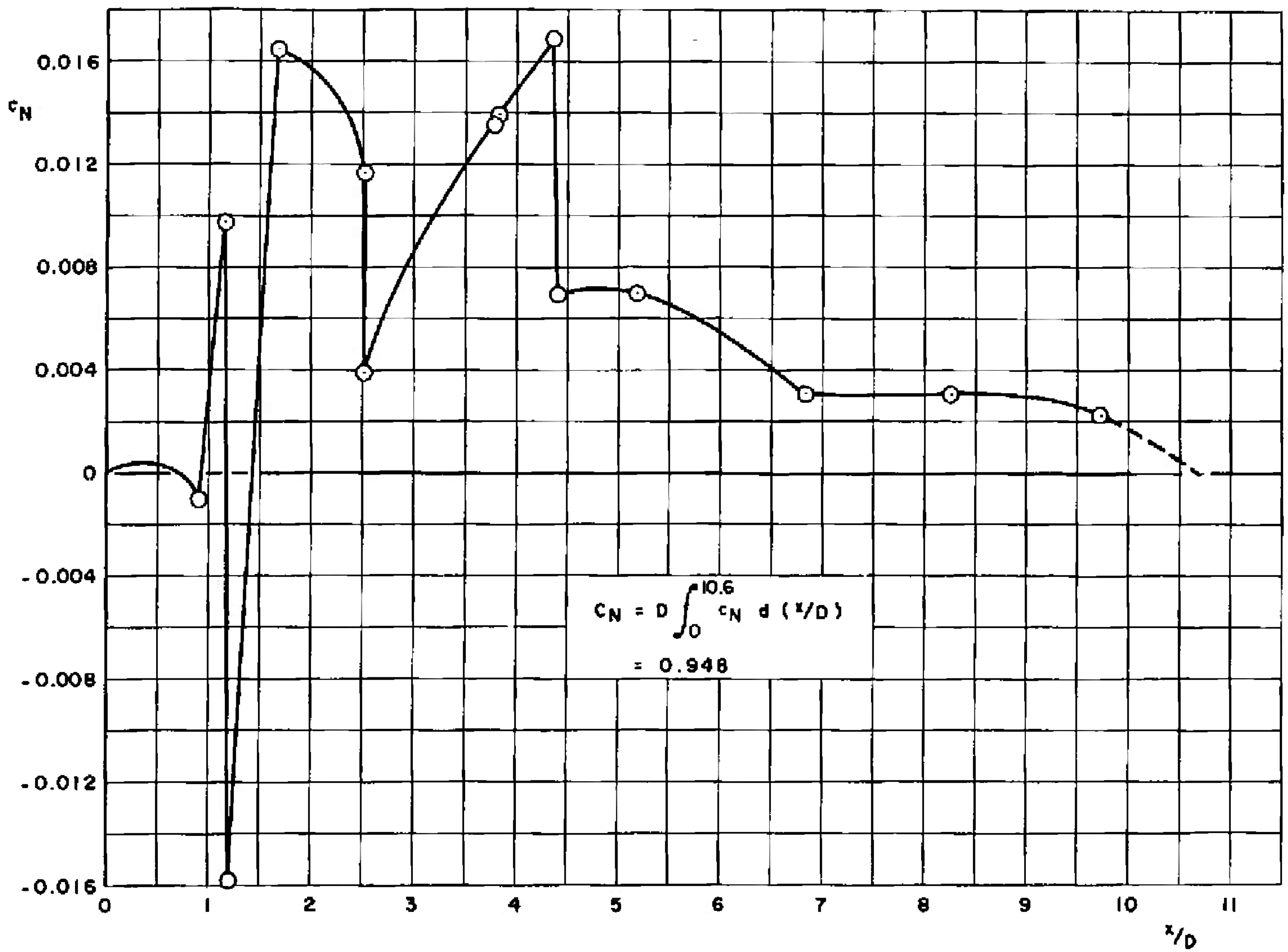


Fig. 12 Section Normal-Force Coefficients, $M_\infty = 1.00$, $\alpha = 10$ deg

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1 ORIGINATING ACTIVITY (Corporate author) Arnold Engineering Development Center ARO, Inc., Operating Contractor Arnold Air Force Station, Tennessee	2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP N/A

3 REPORT TITLE
PRESSURE TEST ON A 0.04-SCALE MODEL OF THE SATURN V LAUNCH VEHICLE AT MACH NUMBERS FROM 0.60 THROUGH 1.45

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)
N/A

5 AUTHOR(S) (Last name, first name, initial)
Brice, T. R., Perkins, T. M., and Robertson, J. E., ARO, Inc.

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
November 1966	48	4

8a CONTRACT OR GRANT NO AF40(600)-1200 b. PROJECT NO. c System 921E. d	9a ORIGINATOR'S REPORT NUMBER(S) AEDC-TR-66-217 9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report) N/A

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13 ABSTRACT

Static pressure distribution and boundary-layer profiles were obtained on a 0.04-scale model of the Saturn V vehicle at Mach numbers from 0.60 to 1.45. The Reynolds number based on the model diameter varied from 3.3 to 6.0 million. Unsteady pressures were also measured over the full Mach number range; however, these data are not presented in this report. Protuberances on the model affected local static pressures, but did not alter the overall distribution significantly.

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	ROLE	WT	ROLE	WT	ROLE	WT
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